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Irrigation Tailwater Management

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This study was undertaken to obtain information and data on irrigation tailwater and other components of irrigation return flows from two representative sites in the Central Valley of California. Extensive data on the quality and quantity of supply and drainage waters were collected for the 1975-77 period from the 664 km^2 Glenn-Colusa Irrigation District and the 113 km Colusa Basin Drain in the Sacramento Valley, and the 1,620 km^2 Mendota-Crows Landing Return Flow Group in the west side of the San Joaquin Valley. The results of this investigation were evaluated to develop conclusions and recommendations on the control and management of irrigation return flows, particularly irrigation tailwater. Because irrigation return flows may be highly variable and their impacts on receiving waters may be also variable, it is suggested that due considerations be given to their site specific nature when developing best management practices.

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It is also hereby declared that the contents of this report do not necessarily reflect the opinions of our cooperators and collaborators, nor of the University of California and U.S. Department of Agriculture. Any opinions expressed herein are solely those of the project investigators.

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FOREWORD

Environmental protection efforts dealing with agricultural and other nonpoint sources have received increased emphasis with the passage of the Clean Water Act of 1977 and the subsequent implementation of the Rural Clean Water Program. As part of this Laboratory's research on the occurrence, movement, transformation, fate, impact and control of environmental contaminants, data and analytical methodologies are developed to assess the causes of and possible solutions to environmental effects of irrigated agriculture.

This report details an effort to characterize the technical, managerial, and economic aspects of irrigation tailwater production in the Central Valley of California. Water quantity and water quality characteristics of actual farm and district systems were measured as a function of commodity crop, irrigation method, cultural practices and water management practices. Economic analyses were performed on specific agricultural enterprises to assess the economic costs and water quality benefits realized for the various alternative management practices studied. This report should benefit farmers, irrigation and drainage district managers, state action agencies, and environmental managers as they attempt to identify and implement pollution control strategies relevant to western irrigated agriculture.

Clinton W. Hall

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ABSTRACT

This investigation was undertaken to obtain information and data on irrigation tailwater and other components of irrigation return flows from two representative sites in the Central Valley of California. Field studies were conducted in the Sacramento Valley where irrigators divert water from the Sacramento River and discharge return flows back into the river, and in the west side of the San Joaquin Valley where irrigators import water from the Sacramento River Basin and discharge return flows into the San Joaquin River.

This report contains extensive data on the quantity and quality of supply and drainage waters for the 1975-77 period. The study sites include the 664 km^2 (164,076 ac) Glenn-Colusa Irrigation District and the 113 km (70 mile) Colusa Basin Drain in the Sacramento Valley, and the 1,619 km^2 (400,059 ac) Mendota-Crows Landings Return Flow Group in the San Joaquin Valley. Within these large spatial units specific water district and farm level studies were also conducted in regard to tailwater production, irrigation and drainage practices and extent of reuse of return flows by agriculture and wildlife areas. Surface irrigation return flows vary widely in both quantity and quality. Site specific conditions and factors contributing to such variations are noted.

The results of this investigation were evaluated to develop conclusions and recommendations on the control and management of irrigation return flows, particularly tailwater. These findings, which were reviewed by local, state and federal water agencies, will contribute to the Section 208 Water Quality Management Planning now being conducted for nonpoint sources of pollutants. Because irrigation return flows may be highly variable and their impacts on receiving waters may be variable, it is suggested that due considerations be given to their site specific nature when developing best management practices.

This report is submitted in fulfillment of Grant No. R-803603 by the University of California under the sponsorship of the U.S. Environmental Protection Agency. This report covers the monitored period March 3, 1975 to March 3, 1977 and was completed on January 10, 1979.

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SYMBOLS AND METRIC UNIT CONVERSIONS

SYMBOLS AND ABBREVIATIONS	DESCRIPTION
B	-- Boron
BOD	-- Biochemical Oxygen Demand
BWD	-- Broadview Water District
Ca	-- Calcium
CBD	-- Colusa Basin Drain
Cl	-- Chloride
DO	-- Dissolved Oxygen
EC	-- Electrical conductivity
EC_e	-- Electrical conductivity of extract
ET	-- Evapotranspiration
GCID	-- Glenn-Colusa Irrigation District
HCO_3	-- Bicarbonate
JTU	-- Jackson Turbidity Unit
K	-- Potassium
MCLRFG	-- Mendota-Crows Landing Return Flow Group
Mg	-- Magnesium
mg/l	-- Milligram per liter
mS/cm	-- Millisiemens per centimeter
N	-- Nitrogen
Na	-- Sodium
NH_4	-- Ammonium
NO_3	-- Nitrate
NO_2	-- Nitrite
NPDES	-- National Pollutant Discharge Elimination System
Organic N	-- Organic nitrogen
P	-- Phosphorus
PDD	-- Panoche Drainage District
pH	-- Acidity
SO_4	-- Sulfate
SS	-- Suspended Solids
TDS	-- Total Dissolved Solids

CONVERSION FACTORS FOR METRIC AND ENGLISH UNITS

To convert column 1 to column 2, multiply by	Column 1	Column 2	To convert column 2 to column 1, multiply by
LENGTH			
0.621	kilometer, km	mile, mi	1.6093
3.281	meter, m	feet, ft	0.3048
0.0394	millimeter, mm	inches, in	25.4
AREA			
247.1	square kilometer, km^2	acre, ac	0.004047
0.004047	square meter, m^2	acre, ac	4,047.
VOLUME			
8.10×10^5	cubic kilometer, km^3	acre-feet, ac-ft	1.234×10^{-6}
0.00081	cubic meter, m^3	acre-feet, ac-ft	1,234
MASS			
1.102	ton (metric)	ton (English)	0.9072
2.205	kilogram, kg	pound, lb	0.454
YIELD OR RATE			
0.0045	tons (metric)/square kilometer, ton/km^2	tons (English)/acre	224.17
0.112	ton (metric)/square kilometer, ton/km^2	pound/acre, lb/ac	8.922
4.46	kilogram/square meter, kg/m^2	ton (English)/acre	0.22
8.922	gram/square meter, g/m^2	pound/acre, lb/ac	0.112
0.892	kilogram, hectare, kg/ha	pound/acre, lb/ac	1.12
FLOW			
0.00981	cubic meter/hour, m^3/hr	cubic feet/second, cfs	101.9
4.403	cubic meter/hour, m^3/hr	U.S. gallons/minute, gpm	0.227
1.699	cubic meter/second, m^3/s	cubic feet/second, cfs	0.0283
MISCELLANEOUS			
3.2808	cubic meter/square meters, m^3/m^2	acre-feet/acre, ac-ft/ac	0.3048
1.359	kilogram/cubic meters, kg/m^3	tons (English)/acre-feet, tons/ac-ft	0.735
1.0	millisiemens/centimeter, mS/cm	millimhos/centimeter, mmhos/cm	1.0
1.0	milligram/liter, mg/ℓ	parts per million, ppm	1.0
0.004047	dollars/square kilometer, $\$/km^2$	dollars/acre, \$/ac	247
1.234	dollars/thousand cubic meters, $\$/10^3\ m^3$	dollars/acre-feet, \$/ac-ft	0.811

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The collaborators and other interested parties also reviewed the conclusions and recommendations offering many helpful suggestions and critical comments.

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trips and technical progress meetings to become personally acquainted with our project activities, including meeting our numerous local cooperators and interested parties. This project also received some financial support from the California State Water Resources Control Board, whose Project Officer was Dr. K. Aref.

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SECTION 1

INTRODUCTION

The Administrator of the U.S. Environmental Protection Agency (USEPA) has a mandate under the 1972 Amendments to the Federal Water Pollution Control Act (PL 92-500) to control the point-source discharge of pollutants into the Nation's waters. This mandate requires the application of "best practicable control technology currently available" (BPT or BPTCA) by July 1977, "best available control technology economically achievable" (BAT or BATEA) by July 1983, and "elimination of discharge of pollutants" (EOD) by 1985. A National Pollutant Discharge Elimination System (NPDES) permit system is being used to implement this mandate.

PL 92-500 does not explicitly identify the control technology desired, but only the goals to be achieved. However, for municipal sewage effluents and many industrial wastewater discharges, uniform waste discharge requirements are being promulgated. For example, secondary treatment of municipal wastewater meets the 1977 BPT goal. Similar effluent discharge requirement/control technology has not been spelled out for irrigation return flows because there are problems of enforcing the control/treatment aspects of the NPDES permits on irrigated agriculture.

Figure 1 identifies the various components of irrigation return flow with a focus on the crop root zone portion of irrigated lands. The "collected" (point source) surface irrigation return flow may be comprised of both surface runoffs and collected subsurface drainage. The former may contain irrigation water surface runoff commonly referred to as "tailwater", operational spills from irrigation distribution systems, and runoffs from precipitation during the irrigation season. The latter may contain collected subsurface effluents from tile drainage and drainage wells, and interception of subsurface water flows by natural and man-made open channels.

Irrigation tailwater, in some quarters, is considered to be the easiest component to manage and control of the point-source surface irrigation return flow. It is said that if tailwater is controlled and/or reused, irrigation application efficiency would be improved, water and energy would be conserved, and, at the same time, discharge of pollutants would be substantially reduced. Although tailwater management appears to be a logical and practical control technology, it has not been thoroughly evaluated with regards to economic, legal, institutional, and physical constraints. Before a blanket recommendation on irrigation tailwater management is made, there is a need to investigate more fully such a management/control policy.

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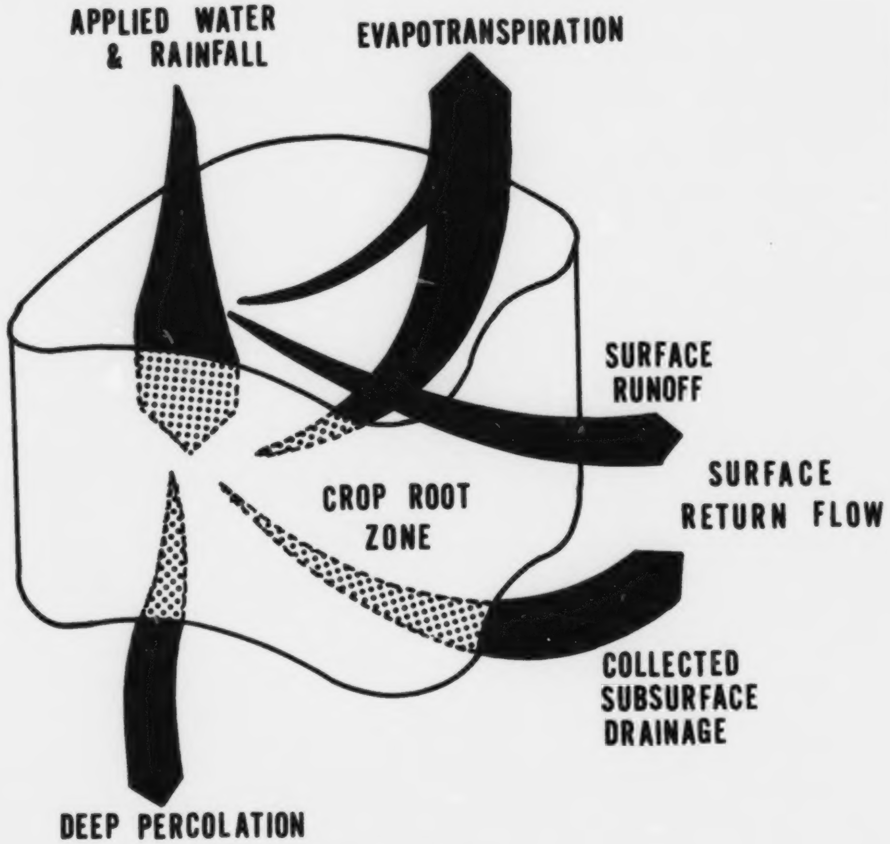
APPLIED WATER & RAINFALL
EVAPOTRANSPIRATION
SURFACE RUNOFF
SURFACE RETURN FLOW
CROP ROOT ZONE
COLLECTED SUBSURFACE DRAINAGE
DEEP PERCOLATION

Figure 1. The major water-flow pathways in the root zone portion of irrigated lands.

Irrigation tailwater control and reuse appears to be a deceptively simple management practice, but in fact may be a very complex practice because of the many factors contributing to and/or affecting tailwater and its quality. To help us understand more fully this potential control technology, field studies were conducted in association with two of California's first and largest NPDES permittees: the Mendota-Crows Landing Return Flow Group (MCLRFG) in the San Joaquin Valley and the Sacramento Valley Water Quality Committee in the Sacramento Valley. These selected operating systems provide case study information and data to the public and policy makers for developing better guidelines for the management of tailwater.

The objectives of this project were:

(1) to identify and evaluate factors contributing to or affecting irrigation tailwater production and its quality,

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(2) to perform field studies in selected areas in the Sacramento and San Joaquin River Basins,

(3) to determine the least-cost combination of agricultural production and labor, capital, irrigation water, and tailwater management and reuse, and

(4) to integrate scientific, engineering, and economic appraisals for the recommendation of guidelines for best practicable technology for irrigation tailwater management.

CAVEAT: PL 92-500, prior to the completion of this report, was amended by the Clean Water Act of 1977 (PL 95-217). The new amendments affecting irrigated agriculture include: 1) Irrigation return flows are reclassified from point to nonpoint sources of pollutants, and hence are exempted from NPDES permits; 2) Irrigation return flows and their cumulative effects are considered under Section 208 Areawide Waste Treatment Management Plans along with other nonpoint sources of pollutants; and 3) a cost-sharing program to be administered by the U.S. Department of Agriculture (USDA) in cooperation with the USEPA will be established to provide technical and financial assistance to landowners and operators in rural areas for implementing Section 208 management plans.

Therefore, some of the conclusions and recommendations made herein are no longer relevant but many of them are still pertinent to Section 208 areawide water quality management planning as well as voluntary efforts in better management of the water resources of the United States.

SECTION 2

CONCLUSIONS

The conclusions are categorized into quantity of tailwater, quality of tailwater, tailwater control and management, and irrigation return flows and PL 92-500. Although these conclusions were generated primarily from case study areas in the west side of the Sacramento and the San Joaquin River Basins in California, they may be generally applicable to other irrigated lands in semiarid to arid climatic regions in California and elsewhere.

A. Tailwater Quantity

1. Tailwater (irrigation surface runoff) is only one of several components comprising surface irrigation return flows.

    a. Other components of "collected" surface return flows from irrigated lands are precipitation runoff, operational spills from distribution systems, effluents from tile drainage and drainage wells, subsurface waters intercepted by natural and man-made open channels, and discharges into irrigation drains by other sectors of society, for example, municipal storm water runoffs and treated sewage effluents.

    b. Tailwater is not usually collected in a drain separate from other collected return flows. In the Central Valley of California the 2.43×10^3-km^2 (0.6 million ac) Westlands Water District is the only large irrigation project that is developing a drainage collection system that separates surface runoff from tile drainage.

    c. Tailwater discharged from irrigated fields may not always reach a receiving surface water body due to evaporation losses, infiltration into the land surface, evapotranspiration by phreatophytes and other vegetation, and recovery and reuse by downstream irrigators and other sectors of society.

    d. In areas where precipitation occurs during the irrigation season, it is difficult to differentiate the magnitudes of runoffs between rain-fed and applied irrigation waters.

    e. In most instances it is difficult to accurately measure tailwater production from a given field because tailwater is produced intermittently, coinciding to irrigation schedules. Unless tailwater is collected in a sump or drain it is usually

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discharged diffusely as a nonpoint source. In this project it was only possible to routinely monitor surface irrigation runoffs from continuously flooded rice fields since the flood waters were spilled from the lowest end of the field through rectangular "check boxes" (weirs), and also from a furrow-irrigated tomato field using a totalizing flow meter on the sump pump of a tailwater recovery system. Other attempts to continuously measure tailwater production on given fields were found to be too difficult and expensive.

2. The factors contributing to and/or affecting on-farm tailwater production are manifold.

   a. In areas where water is scarce or expensive, tailwater is seldom discharged or, if produced, is generally reused at or close to the site of production. Although the price of water is not the only factor dictating water reuse, a general observation indicates that as irrigation water costs increase tailwater recovery systems become economically advantageous. Also in times of drought conditions, such as the 1977 drought in California, irrigation water is more carefully managed and reuse is more extensively practiced.

   b. In areas where water is plentiful or inexpensive, there is a tendency for large water applications and production of tailwater. The production of tailwater, however, does not mean inefficient water management since reuse is commonly practiced.

   c. The tailwater produced is usually captured and reused, either by plan or incidentally, at the site of production or downstream.

      (1) The reuse of tailwater and other collected return flows may occur at several spatial levels, for example, within an individual irrigated field, on-farm (i.e., capture and reuse in downslope field by landowner), district level (irrigation, drainage, reclamation), and up to river subbasin, river basin, and interbasin levels.

      (2) The types of beneficial uses made of tailwater and other collected irrigation return flows include irrigation of crops and pasture, maintenance of wetland/waterfowl habitats, livestock water supply, groundwater recharge, maintenance of summer (low) flows in stream beds which would otherwise become dry, repulsion of salinity in tidal estuaries, fish migration and spawning, warm water fish habitat, navigation, recreation and aesthetics, and municipal/industrial water supply.

      (3) Some of the above beneficial uses are partly to wholly dependent on irrigation return flow as the principal source of supply water.

d. One of the major factors contributing to the production of tailwater is irrigation application method.

(1) Surface flood irrigation methods (basin, border, furrow), have inherent limitations making it difficult to attain high application efficiencies. The slope of the irrigated field, length of run, size of stream used, and water intake (infiltration) rates are some of the critical factors affecting tailwater production. These critical factors must be balanced within a system to obtain efficient water application.

(2) In 1972, California had about 41% of the croplands irrigated by the basin/border method, 34% by furrow, 18% by sprinkler and the remainder by subirrigation, drip (trickle) irrigation, and others. Although sprinkler and drip irrigation methods are being increasingly used, it is anticipated that surface flood irrigation will continue to be the most used method in California and elsewhere.

(3) Tailwater is less frequently produced in well-designed and properly-managed sprinkler and drip irrigation systems. In surface flood irrigation, however, it is difficult to attain application efficiencies in excess of 85% for basin and border methods and 90% for furrow method. It is exceedingly difficult to completely eliminate runoffs from flood irrigation methods other then from level borders and basins or level furrows.

(4) The estimated runoffs and attainable irrigation system efficiencies cited above are dependent not only upon system design but also upon technical skills of irrigators.

(5) Tailwater is unavoidable under certain conditions and cultural practices such as in paddy rice culture, with continuously flooded fields, and other crops that require frequent but light applications during seed germination in furrow beds.

(6) In addition there are institutional and operational constraints that contribute to or affect tailwater production. In Colorado, reuse of irrigation tailwater is prohibited where there are downstream users of this return flow. Broadview Water District (BWD) in the San Joaquin Valley does not have a right-of-way to discharge surface irrigation return flows into contiguous lands and the San Joaquin River; hence, the district practices complete recirculation and reuse of collected irrigation return flows. Some irrigators and districts do not have complete choice of when and how much water is to be delivered/distributed to them due to unique water delivery policies and/or water rights. These constraints may contribute to inefficient water management and greater tailwater production.

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B. Tailwater Quality

1. The quality of tailwater usually is similar to that of the applied water but could be quite variable, sometimes an improvement and other times a deterioration in overall quality and/or specific parameters.

    a. The quality of applied water usually has a strong influence on the quality of tailwater. Except for sediments, tailwater quality is generally expected to be similar to applied water.

    b. In some instances tailwater quality may be considerably degraded because of the pickup of dissolved mineral salts, sediments, and agricultural chemicals.

    c. In other instances tailwater quality may be improved over that of the applied water. This is possible because of the deposition of suspended solids which may contain sorbed agricultural chemicals as well as the potential reduction of degradable pollutants as in flooded rice fields.

    d. Significant changes in tailwater quality may occur abruptly over a short time period or over an extended period. For instance, aerial applications of ammonium sulfate fertilizer in rice fields may result in a pulse of ammonia (NH_3) and nitrates (NO_3) in the runoff waters over a two-to-four-day period whereas suspended solids in the flood waters are significantly reduced by sedimentation over the rice growing season.

2. Suspended matter is frequently the quality parameter of most concern in tailwater.

    a. Water passing over the land surface has a tendency to erode the soil and to transport both mineral and organic matter in a suspended form.

    b. Associated with these suspended matter are several classes of water quality constituents such as sorbed pesticide residue and other toxicants like certain metals and boron (B), nutrients like phosphorus (P) and nitrogen (N), and certain soil minerals like gypsum ($CaSO_4 \cdot 2H_2O$) which may later dissolve in the water contributing to a rise in salinity.

    c. Thus, the reduction of sediments in tailwater will not only help in minimizing the undesirable impacts of sediment per se, but also decrease the discharge of pollutants associated with the sediments.

3. Other pollution and/or quality parameters in tailwater may be of importance for site-specific conditions and practices.

a. Evaporite minerals (highly soluble salts such as $NaCl$, Na_2SO_4, $MgSO_4$, etc.) that are naturally present in the soil surface or accumulate in furrow beds may contribute to increase in salinity in the tailwater over that of the applied water.

b. Nitrogen may be picked up by tailwater in both organic and inorganic forms as well as dissolved and particulate forms. In general, runoff waters from close-growing crops (e.g., rice and pasture) contain a predominance of organic nitrogen over that of inorganic forms (NH_3, NO_3, NO_2) and vice versa from widely-spaced crops (e.g., row crops).

In the reuse or renovation of high nitrogen-containing wastewaters, however, large reduction in nitrogen in the effluent may be achieved by passing water overland on grasslands or in anaerobic ponds. The reduction is attributed to denitrification and assimilation by plants.

c. Phosphorus, like nitrogen, exists in many forms. In general, the concentration of dissolved phosphorus is low in tailwater due to the low solubility of phosphorus compounds. However, significant amounts associated with mineral and organic matter may be discharged in runoff.

d. Pesticide residue may be present in tailwater, but the concentrations of pesticides are highly variable both in time and location. This is due to the wide variability in mode of applications, formulations, soil interactions, and chemical properties such as solubility, volatility and biodegradability.

e. Dissolved oxygen (DO) in tailwater also varies but seldom is a problem. DO in tailwater is usually lower when the biochemical oxygen demand (BOD) is present in significant amounts. DO in tailwater may be increased by aeration as it flows over structures or absorbs oxygen produced during respiration by aquatic plants such as rice.

4. The quality of tailwater is usually different from operational spills and collected subsurface drainage waters.

a. The quality of operational spills is similar to the supply water whereas subsurface drainage waters usually contain higher concentrations of salts and nitrogen and lower concentrations of suspended solids (SS).

b. These quality differences are illustrated by a comparison between the Glenn-Colusa Irrigation District (GCID) in the Sacramento Valley and Panoche Drainage District (PDD) in the San Joaquin Valley. The electrical conductivity (salinity) and turbidity (suspended matter) of the supply waters for PDD are nearly the same as that of the drain waters from GCID. The salinity and turbidity of collected irrigation return flows from PDD are exceedingly high because the tile drainage effluents are extremely saline due to the presence of native soil salts and the soils are highly erodible, respectively. Although the organic-N and NH_4-N concentrations are similar for both supply and drain waters in these two districts, NO_3-N is not. The NO_3-N content is very high in PDD due to the leaching of native soil N into the tile drains while there is no underdrainage practiced in GCID.

C. Tailwater Control and Management

1. There appears to be no one universal control technology for tailwater and other collected surface irrigation return flows due to the wide variability in the quantity and quality of supply waters and return flows.

    a. The various management practices may include one or more of the following: improve irrigation application efficiencies to attainable levels, capture usable irrigation return flows, discharge tailwater only as required by cultural practices, install sediment retention sumps or other facilities, install tailwater recovery system and reuse at farm site, allow for limited tailwater discharge under either low stream flow conditions to augment/maintain flow when it is desirable or under high stream flow conditions to minimize impact of pollutants discharged, and elimination of discharge of tailwater. The above technology is available but in some the systems or water controls needed are so costly that current conditions do not justify them. For instance, to allow for limited tailwater discharge under either low or high stream flows may require large holding reservoirs if the timing between tailwater production and discharge allowed into streams do not coincide.

    b. The application of the foregoing array of possible technology should be site-specific. Although there may be some that can be broadly applied, there is no single, universally-applicable control technology for irrigated agriculture. Elimination of tailwater at all sites is not practical or feasible.

2. The control technologies also may be viewed in terms of source control, effluent treatment, and reuse.

    a. In some instances, the most practical means of managing tailwater may be source control, i.e., reduction of tailwater.

        (1) A properly designed and operated sprinkler or drip irrigation system should produce no tailwater, but with surface flood irrigation methods some tailwater production is usually inevitable.

        (2) Low application efficiencies of surface flood methods can be improved with land grading, contour irrigation,

by changing stream size or by changing length of run. Education of the operating personnel may be effective in reducing tailwater.

b. In other instances, tailwater control and management may involve effluent treatment.

(1) Where sediments appear to be the major quality problem for tailwater, sediment removal practices may be appropriate. Sediments could be removed in retention ponds or tanks, vegetated buffer strips like grass and barley, and other small-scale on-farm facilities. Off-farm, sediments in collected irrigation return flows may be incidentally deposited during reuse in irrigated pastures, and duck and fish ponds as in the Grassland Water District (GWD) and Wildlife Refuges in the San Joaquin Valley.

(2) Not all the sediments found in irrigation drainage canals come from tailwater. Sediments deposited in channels during winter storm runoffs may be resuspended in drains with increased current velocity as in the Glenn-Colusa Irrigation District. Other sources may include erosion of drain banks as in Panoche Water District.

(3) Under certain conditions, in spite of carefully implemented sediment control and retention practices, some sediments due to their unique mineral characteristics are highly dispersed and may require chemical treatment to induce sedimentation. Such is the case of Tehama silt loam in the Sacramento Valley or sodium-affected soils along the basin in the Central Valley.

(4) For return flows containing significant amounts of subsurface drainage water in addition to surface runoff, salts and nitrogen may be a problem requiring some treatment. Desalting and nitrogen removal technology have been investigated at the Firebaugh Wastewater Treatment Facility in the San Joaquin Valley.

c. Another alternative for tailwater control and management is "recovery and reuse".

(1) Where there are no quality or quantity constraints in the use of tailwater and other irrigation return flow components, the tailwater may be captured and directly reused. For example, GCID at the district level captures and reuses about one-half of the drain waters produced. The remainder is discharged into the Colusa Basin Drain where further reuse is made downstream. The timing of availability of drain water frequently does not correspond to irrigation demands. For the Colusa Basin Drainage Area, where on-farm irrigation efficiencies are comparatively low due to paddy

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rice culture, the overall basin irrigation efficiency over a 10-year period, however, was estimated to be about 70% mainly due to reuse. The Panoche Drainage District and a contiguous district, Central California Irrigation District, capture from 20 to 30% of the drain waters produced in PDD and the remainder is discharged into the Grasslands Water District for pasture irrigation and duck ponds. In some areas of the San Joaquin Valley, tailwater is sold to neighbors.

(2) Where there are quality or quantity constraints, irrigation return flow may be utilized by blending with freshwater. In Broadview Water District, all of the collected irrigation return flow generated within this District and some inflows from upslope irrigators is captured and reused. The irrigation supply water is on the average a 50-50 blend of canal water and captured saline return flows for this San Joaquin Valley water district.

(3) When the quality is no longer suitable for crop irrigation, other beneficial uses are available for irrigation return flows. For example, the Los Banos Wildlife Area (LBWA) in the San Joaquin Valley diverted drainage waters for use in ponds and marshland, as well as irrigation for feed and cover for wildlife.

3. The least-cost combinations of agricultural production and labor, capital, irrigation water, and tailwater management and reuse were analyzed for a variety of alternative on-farm irrigation systems of varying sizes.

a. Economic-engineering cost studies of several field-level (0.688 km^2, 170 ac) alternative irrigation systems indicate that systems designed to minimize tailwater discharge will lower annual irrigation costs compared to a conventional furrow method. These cost savings are primarily due to the lower water and labor requirements. These studies are based on the 1976 interest rates, input prices, and water application rates for a 0.688 km^2 tomato field in the San Joaquin Valley study area. The alternatives considered are as follows:

(1) A side-roll sprinkler system with the lowest labor requirement has the lowest cost per unit area (\$0.0316/m^2, \$128/ac) of the alternatives analyzed.

(2) A furrow-irrigation method using gated pipe and a tailwater reuse system has an annual irrigation cost of \$0.0371/m^2 (\$150/ac). This compares favorably with the conventional furrow and siphon method costing \$0.0437/m^2 (\$177/ac).

(3) A hand-move sprinkler system was also less expensive than the conventional furrow and siphon method, having a cost of \$0.0376/m^2 (\$152/ac).

(4) If an interest rate of 10% rather than 8% and a wage rate of \$3.50 rather than \$4.50 per hour are assumed, then the differences in cost are smaller. However, the water-efficient systems are still less expensive on an annual basis than the conventional furrow and siphon system.

(5) If the cost of delivered water were higher than the \$0.00486/m^3 (\$6/ac-ft) assumed price, then the savings over the conventional method would be more pronounced. Likewise, if the water cost were substantially lower than \$0.00486/m^3, it appears that furrow and flood irrigation would be most cost effective.

The above analysis applies to a low-growing crop like tomatoes. It would not be possible to use side-roll sprinklers for tall-growing crops like corn and cotton.

b. The profitability of augmenting the water supply of a 6.78 km^2 (1675 ac) tile-drained farm with recaptured drainage water depends on the relative costs and qualities of the supply and recaptured waters. These results are based upon assumed boron concentrations of 0.1 and 2.5 mg/l for supply and recaptured waters, respectively.

(1) If delivered supply water costs \$0.0162/m^3 (\$20/ac-ft), the net returns are increased (\$0.00395/m^2, \$16/ac) by recapturing all of the on-farm return flows and an additional 3.21 x 10^6 m^3 (2604 ac-ft) from available district drainage water. An average blend of supply and captured water consisting of 76% recaptured water was found to be most profitable under these conditions.

(2) If the cost of the delivered supply water is only \$0.00405/m^3 (\$5/ac-ft), a \$0.000494/m^2 (\$2/ac) increase in net returns results from recapturing up to 2.02 x 10^6 m^3 (1637 ac-ft) of available off-farm drainage water.

4. Tailwater control and reuse may be desirable in some instances, but this practice must be viewed in the light of other water management plans and policies.

a. A large reduction in tailwater and other collected return flows may lead to other potential problems such as a diminished supply of water for subsequent or downstream water users, a diminished summer flow in streams, and/or an inadequate stream flow to repel seawater intrusion. The summer flows in the middle reaches of the San Joaquin River are primarily due to irrigation return flow. It is also estimated that irrigation return flow

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into the Sacramento River contributes about 25% of the flow in July and August.

b. If water is conserved within a basin and less water is diverted by irrigators, such conservation practices would be negated if the water saved is utilized for other purposes and not kept within the stream system. This problem becomes more complex when interbasin transfers of water are involved. There appears to be no clear-cut policy on the disposition of water saved through conservation practices in the import area.

c. Although on-farm source control of tailwater and other components of irrigation return flows may be more profitable under some conditions, legal, institutional and physical constraints exist which limit basin-wide curtailment of tailwater.

(1) The Los Banos Wildlife Area recaptures about 15.4 x 10^6 m^3 (12,500 ac-ft) of drainage water each year. The value of this water for waterfowl hunting alone was estimated to be \$0.00525/m^3 (\$6.47/ac-ft).

(2) In some instances, irrigation districts depend heavily on irrigation return flows for their supply water.

(3) It is possible that any requirement to eliminate tailwater will encourage an increase in irrigated acreage. There is insufficient information to ascertain under what conditions tailwater control will aggravate other subsurface and surface return flow problems. Furthermore, it is more difficult to ascertain the impact it will have on basin water quantity/quality problems.

(4) The least-cost pollution control strategy for any area may involve any one or a combination of regulations, technologies, best management practices, or effluent taxes. A basin-wide economic analysis, including the costs of implementing and/or enforcing such policies, is needed to determine the least-cost strategy of achieving any given level of water quality.

D. Irrigated Agriculture and PL 92-500

1. Irrigated agriculture has a unique physical nature and institutional structure for which the effluent guidelines promulgated in PL 92-500 cannot be applied as reasonably as in most other industries. It is the contention of the authors that irrigated agriculture does not have the "plumbing and valves and holding tanks" of a "closed system" found in industrial plants and sewage treatment plants. In contrast, irrigated agriculture operates in an "open system" in which many of the natural conditions and processes are unmanageable/uncontrollable by man, or, at best, difficult to manage. Thus, if irrigated agriculture is to comply with the intent of PL 92-500, this industry

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would require pollution abatement controls and policies different from those of most other industries.

2. The 1985 goal of attaining "elimination of discharge", i.e., no discharge of pollutants greater in concentration than that of the original supply water, is unrealistic if applied to irrigated agriculture. During the growth of a crop the process of consumptive use of waters by plants results in an increase in salt concentration in the soil. Thus the return flow water would be degraded relative to the supply water. If this goal is pursued, the elimination of discharge of accumulating salts would seriously impair the productivity of irrigated lands. The National Commission on Water Quality in its report to Congress on March, 1976 recommended that some discretion be used when applying PL 92-500 to irrigated agriculture. Provisions are being made to allow for some incremental increases in pollutant concentration in irrigation return flows.

3. There is a potential danger that control of point-source surface irrigation return flows may result in the transfer of pollution and other problems from surface to ground water bodies, for example, rising water tables that cause drainage as well as salinity problems. Such an inflexible control strategy should be considered carefully since the replacement (turnover) and travel (transit) times to ground waters are much longer than those for surface waters. Ground water pollution may take decades to develop; and therefore, it may also take decades to correct.

4. A reduction in irrigation return flow, tailwater in particular, may result in greater water-use efficiency and higher concentration of pollutants, but lower mass emission. Although it is recognized that concentration (mass per unit volume of water) is an important parameter for evaluating water quality and the impact on beneficial uses, mass emission (concentration times volume of water) and unit mass emission rate (mass per unit area irrigated) need to be considered in source control. If concentration is overly stressed, this tends to promote inefficient resource use.

5. It is often difficult to differentiate the sources of pollutants between man-induced and natural conditions. In many sites, it is difficult to monitor water flow due to lack of suitable structures and prohibitive costs of setting up gaging stations, especially where flow reversal may occur. The quantity and quality of irrigation return flows are highly variable, reflecting local differences in hydrologic and geologic conditions, soil properties, cropping patterns and cultural practices, supply water, and the extent of reuse. For the reasons cited, source control or best management practices (BMP) may be preferred over waste discharge requirements.

6. At the present there does not appear to be strong incentives for water pollution control in irrigated agriculture partly due to the difficulties in adoption of technology to attain the goals of PL 92-500. It is true, however, that with the advent of the NPDES

permit system most permittees are now cognizant of the quantity and quality of their return flows. Some management plans have been implemented to utilize more fully the usable wastewaters.

7. The complex nature of water law and water rights in the western states may present difficulties in effectively managing water quality and quantity problems. Likewise, certain management concepts may prove unfeasible due to the adverse effect on downstream water users who have long established rights and facilities to beneficially use irrigation return flows.

8. An NPDES permittee is usually formed from existing institutional structures and political boundaries. However, at the present time it does not appear to have a broad base of authority over issues within its jurisdiction.

SECTION 3

RECOMMENDATIONS

A. Guidelines for Water Quality Control for Irrigated Agriculture

1. Due to the great variability in the quantity and quality of "collected" surface irrigation return flows, irrigated agriculture requires pollution abatement controls and policies different from most other industries. The regulatory controls proposed for irrigation return flows should be flexible, reasonable, and attainable.

2. Since irrigated agriculture operates in an "open system" in contrast to a "closed system" as in most other industries, best management practices (BMP) and source control should be considered. This is in contrast to the prevalent practice of relying on waste discharge requirements and "end-of-pipe" treatment technologies for municipal and industrial discharges.

3. Irrigation return flows and the resulting waste loads range widely in controlability. Management and controls should be adopted on the basis of both cost and technical efficiency.

4. Site-specific factors and conditions on a case-by-case basis should be considered in developing regulatory guidelines, controls, or standards. Local, as well as state-wide, standards should be developed which are in conformance with the national goals. These site-specific plans and management, however, should be compatible and mutually beneficial at the basin and interbasin levels.

5. Policies and guidelines developed for pollution control for irrigated agriculture should be integrated with other ongoing control plans and management, for example the area-wide 208 planning efforts. Long-term rather than short-term effects should be emphasized in order to maintain productivity in irrigated agriculture.

6. The impact of pollutants is usually assessed in terms of concentration, but for control purposes, mass emission (concentration x volume) should also be considered.

7. A thorough review and evaluation of water rights and water laws should be undertaken, in order to determine the extent of potential

conflicts with the achievement of the objectives of PL 92-500. Likewise, PL 92-500 should also be thoroughly reviewed.

8. As an alternative management policy improving the quality of receiving waters by taxing irrigation return flows should be considered because it allows dischargers the flexibility to respond in a least cost manner. An effluent tax based on mass discharge could be considered as a policy option in certain areas where the quantity and quality of discharges from any one water user are independent of those of any other user in that area.

   Such a policy, however, may tend to favor dischargers in areas of limited or no discharges because of the high cost of water and/or limited supply of water. It is anticipated that there would be problems in implementing and enforcing such a policy with regards to whom will be the responsible agency, what are the criteria for taxable mass discharges and who would be the recipient of the effluent tax.

9. To be more effective, the current NPDES permit system should be modified.

   a. To avoid unnecessary fragmentation and to facilitate monitoring and control, NPDES permits should be applied to spatial units which preferably have common hydrologic boundaries. Those entities having no direct outfalls to major tributaries should consolidate with contiguous entities through which either surface and/or subsurface flow could occur. This is being done in the Central Valley of California.

   b. It is recommended that the current self-monitoring of flow and quality constituents of supply and discharge waters be continued. The particular quality parameter to be measured should be dictated on the basis of local problems and needs. The monitoring period should encompass the irrigation season including the lag time, if any, between cessation of irrigation and discharge. For many sites year-round monitoring is desirable. The service area or drainage area should be identified for each monitoring station and information and data reported for each subunit. The number of monitoring stations, and method and frequency of measurements should be dictated by local conditions. Internal monitoring stations would be desirable for permits covering extensive land area and/or receiving waters.

   c. If a particular water quality problem has been identified, background information and baseline data listed below would be useful. It is recognized that these items are extensive and some are not readily available, but it is from such information and data base that reasonable, flexible, and attainable controls and policies could be developed. These are:

(1) Location map and description of area (precipitation, growing season, dominant soil types and properties, irrigated acreages and cropping patterns, etc.).

(2) Water supply (sources and qualities, total quantity and seasonal distribution, water rights, etc.).

(3) Irrigation and drainage systems (district/project distribution and lateral systems, on-farm systems, unit rates for applied and drainage waters).

(4) Application and mass emission rates of agricultural chemicals.

(5) Any other unique features or problems such as saline seeps.

B. Guidelines for Irrigation Tailwater Control and Management

1. Improve irrigation efficiencies.

   a. Training programs on irrigation management and practices, particularly improving efficiency of surface flood methods, should be conducted.

   b. Irrigation water should be applied in amounts needed for crop evapotranspiration, and salt control, seed germination, frost protection, and other such special cultural requirements.

   c. For surface flood irrigation methods in particular, additional research and demonstration activities are needed to provide better water control by operators, better irrigation system design criteria, and better irrigation scheduling.

   d. Improved water measurement techniques/devices are needed for monitoring soil water and irrigation inflows and return flows.

2. Tailwater and other usable collected irrigation return flows should be recovered and reused whenever this practice will be a cost effective method of improving water quality.

   a. For locations where the collected subsurface waters are considerably more degraded in quality than surface runoff, attempts should be made to keep these two types of irrigation return flows separate so that the surface runoffs will have greater reuse potential for all sectors of society.

   b. Under certain conditions, it may be more operationally efficient to capture and reuse water at larger spatial levels than field-site and farm-site, e.g., water district, irrigation project, or basin.

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c. The irrigation return flows, especially if the quality is significantly degraded, may have other beneficial uses such as maintenance of marshland or wetland habitat.

d. The technology, in general, is available for capturing tailwater, and other return flows. However, further studies are needed to evaluate operational efficiencies, economics, and water quality improvement when using such systems.

3. Where there are detrimental impacts due to the sediment load in tailwater, sediment source control practices and/or sediment removal operations should be considered.

   a. Under conditions of moderate to high erosion hazards, particularly with surface irrigation methods such as wildflooding, corrugations and furrows, source control practices should be implemented, including better control of water by reducing the length or run and slope or contouring.

   b. Where the sediment load in tailwater is a problem, sediment retention facilities should be built. Sediment removal may consist of sedimentation tanks or ponds, vegetated buffer strips at the end of irrigated fields and water spreading over contiguous grasslands and ponds.

   c. The benefits of sediment control and/or removal are multifaceted, for example, removal of sediments also decreases pesticide and phosphorus emissions. These technologies are probably the most important practices of concern in tailwater quality at many sites.

4. Other more stringent controls may be necessary depending upon site-specific conditions.

   a. The discharge of tailwater should be minimized during and immediately after the application of agricultural chemicals (for instance, injection of anhydrous ammonia in irrigation water, aerial top-dressing of fertilizers and herbicides on flooded rice fields, etc.) to prevent pulses of pollutants from being discharged into receiving waters.

   b. It may be desirable to limit the discharge of tailwater except as required by necessary cultural practices, such as seed germination in furrow beds.

5. Still other tailwater control and management practices may be considered as alternatives when the conditions merit them.

   a. In some cases it may be desirable to discharge tailwater under low stream flow conditions to augment/maintain flow. For other cases it may be desirable to discharge tailwater under high stream flow conditions to minimize the impact of pollutants

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discharged into the receiving stream. Under extremely hazardous conditions it may be necessary to prohibit discharge of tailwater.

b. The foregoing alternative controls and practices should not be broadly applied and enforced, but taken on a case-by-case basis. Some of them require extensive structural modifications including water control. The least cost combination of alternatives may be recommended to achieve specified goals such as level of water quality.

6. Wherever possible, the resources and expertise available in line agencies (USDA-Agricultural and Economic Research Services, Soil Conservation Service, U.S. Bureau of Reclamation, Agricultural Experiment Stations and Cooperative Extension Services, and other state agencies) should be utilized to develop and implement Best Management Practices.

7. Where there appears to be no incentives or tangible benefits for irrigators to implement water quantity/quality control measures, cost sharing, low interest loans, and other incentive programs should be explored in order to equitably distribute the financial burden of maintaining water quality.

8. Due to the site variability of receiving waters, and of tailwater production and quality, the authors do not recommend any single universally applicable control technology. The effect(s) of tailwater discharge into surface waters may be either beneficial, detrimental or both, depending on the quality constituents of interest and water flow. A practice that is effective in one location may not be as effective in another.

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SECTION 4

BACKGROUND AND SCOPE

NPDES PERMIT SYSTEM

As mandated by PL 92-500, EPA adopted a policy in 1973 to require NPDES permits for irrigators to discharge surface return flows from irrigated lands having an area greater than 12.1 x 10^6 m^2 (3,000 ac). The permit required reports on water quantity-water quality data to establish a data base from which waste discharges could be specified in the future. The Natural Resources Defense Council (NRDC) challenged the 12.1 x 10^6 m^2 permit exemption and in June 1975 the Federal District Court of Columbia issued an opinion (Flannery Decision) disallowing this exemption. EPA was required to issue permits regardless of the size of the irrigated area covered by the permit.

In some states, the issuance of NPDES permits was directly handled by the EPA Regional Offices while in other states this authority was delegated to the state. In California, the NPDES permits are administered by the State Water Resources Control Board through the nine Regional Water Quality Control Boards.

The first two permits issued in July 1975 by the Regional Water Quality Control Board - Central Valley Region were to the Mendota-Crows Landing Return Flow Group in the San Joaquin Valley and the Sacramento Valley Water Quality Committee in the Sacramento Valley. These NPDES permittees were required to self-monitor and report the water flow, electrical conductivity, and suspended solids of their irrigation supply waters and surface irrigation return flows. Since July 1975 this Regional Board (Merrill, 1977), having jurisdiction over 27.8 x 10^3 km^2 (6.86 million ac) of irrigated croplands, issued a total of 22 permits covering about 11.7 x 10^3 km^2 (2.9 million ac) of croplands.

When PL 92-500 was amended by PL 95-217 in 1977, the Advisory Committee on Agricultural Water Problems made the following five recommendations to the State Water Resources Control Board:

1. Abandon the present NPDES irrigation return flow monitoring program.

2. The Regional Board should assemble and assess all available information and data collected from the NPDES irrigation return flow monitoring program, and existing data from other agencies of government.

3. The Regional Board and the irrigation return flow permit groups should continue the monitoring of irrigation flows under a voluntary agreement where this would be mutually beneficial to both interests.

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4. The Regional Boards will provide all pertinent data collected in the past and in the future to the PL 92-500 Section 208 planning process.

5. Where water quality problems have been identified and where the cooperating effort is lacking, then as a last resort, the Regional Boards should implement the Waste Discharge Requirements as authorized under the California Porter-Cologne Water Quality Control Act of 1970.

SCOPE OF PROJECT

EPA Grant No. R-803603, Irrigation Tailwater Management, was initiated in March 1975 for a two year period and later extended for six more months. Supplemental financial support was also provided by the California State Water Resources Control Board under Standard State Agreement No. 4091400 for the period June 1975 to March 1976.

In spite of the extensive information and data available on irrigated agriculture, the data were deemed to be inadequate to appraise the potential impacts and feasibility of implementing PL 92-500. A major objective of this project was to monitor and evaluate surface irrigation return flows in selected NPDES permit areas and to develop a more comprehensive data base that would serve as a case study for other project objectives.

Field work was conducted in California's first two NPDES permittees. In the Sacramento River Basin (Figure 2), the 0.664 x 10^3 km^2 (164,000 ac) Glenn-Colusa Irrigation District and the 113 km (70 mile) Colusa Basin Drain were monitored. The former is one of forty-five entities making up the NPDES permittee known as the Sacramento Valley Water Quality Committee representing about 4.05 x 10^3 km^2 (1 million ac) of irrigated lands, and the latter is one of the two largest drains discharging return flows into the Sacramento River system. Field work was also conducted in the 1.62 x 10^3 km^2 (400,000 ac) Mendota-Crows Landing Return Flow Group in the San Joaquin River Basin (Figure 2) representing 17 entities. In both study locations, monitoring was conducted in the irrigation as well as nonirrigation seasons and over spatial scales ranging from irrigated fields to water districts, and aggregates of districts.

Based on these field studies and other sources of data, the factors contributing to or influencing the quantity and quality of irrigation return flows were evaluated. The data from field sites were also used to make cost analyses for irrigation systems and water management practices. Finally, the scientific engineering, and economic data and appraisals were integrated to develop guidelines for best practicable control technology on irrigation return flows.

SCOPE OF THIS REPORT

This report highlights the more important findings of this project by summarizing the field evaluations as well as the conclusions and recommendations. Publications and presentations eminating from this project are listed on pages 112-114. They include two comprehensive annual progress reports for 1975-76 (Tanji et al., 1976, 200 pp.) and 1976-77 (Tanji et al., 1977, 245 pp.), both of which will become available from the National Technical Information Service (NTIS). It would not be practical herein to present all of the information and data collected except for the nature and summary of such with due references made to the annual reports.

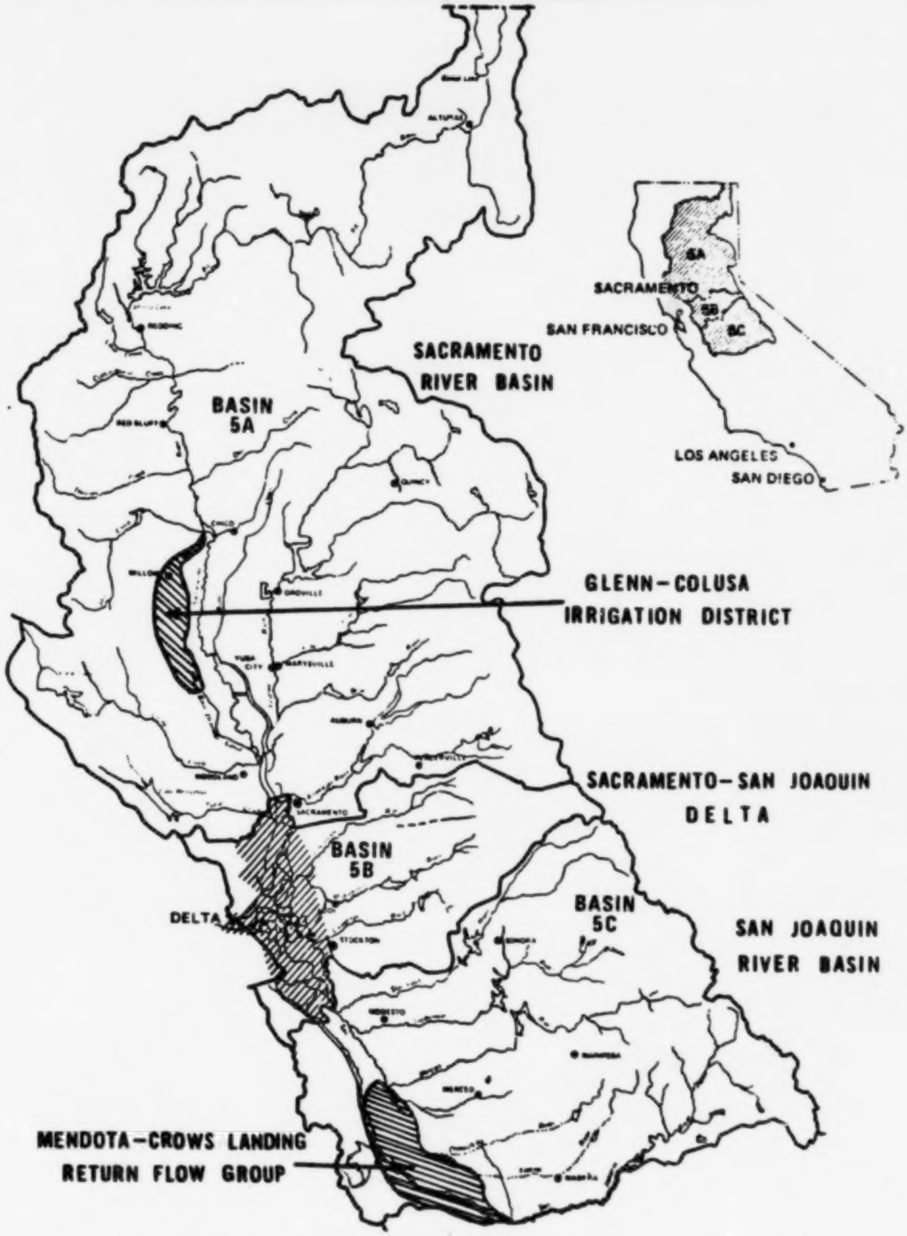

SACRAMENTO
SAN FRANCISCO
5A
5B
5C
LOS ANGELES
SAN DIEGO
SACRAMENTO RIVER BASIN
BASIN 5A
GLENN-COLUSA IRRIGATION DISTRICT
SACRAMENTO-SAN JOAQUIN DELTA
BASIN 5B
DELTA
BASIN 5C
SAN JOAQUIN RIVER BASIN
MENDOTA-CROWS LANDING RETURN FLOW GROUP

Figure 2. General location map of the field study sites in the Sacramento and San Joaquin River Basins.

SECTION 5

FIELD INVESTIGATIONS

SELECTION OF FIELD STUDY AREAS

The selection of the field study sites was closely coordinated with the California Regional Water Quality Control Board - Central Valley Region and the NPDES permittees, Mendota-Crows Landing Return Flow Group and the Sacramento Valley Water Quality Committee. The Great Central Valley (Sacramento and San Joaquin Valleys) was chosen as the general study area since it contains about 75% of the total irrigated lands (36.83×10^3 km^2 or 9.1 million ac) in California and uses about 77% of the total water used in irrigated agriculture (41.9 km^3 or 34 million ac-ft) in the state.

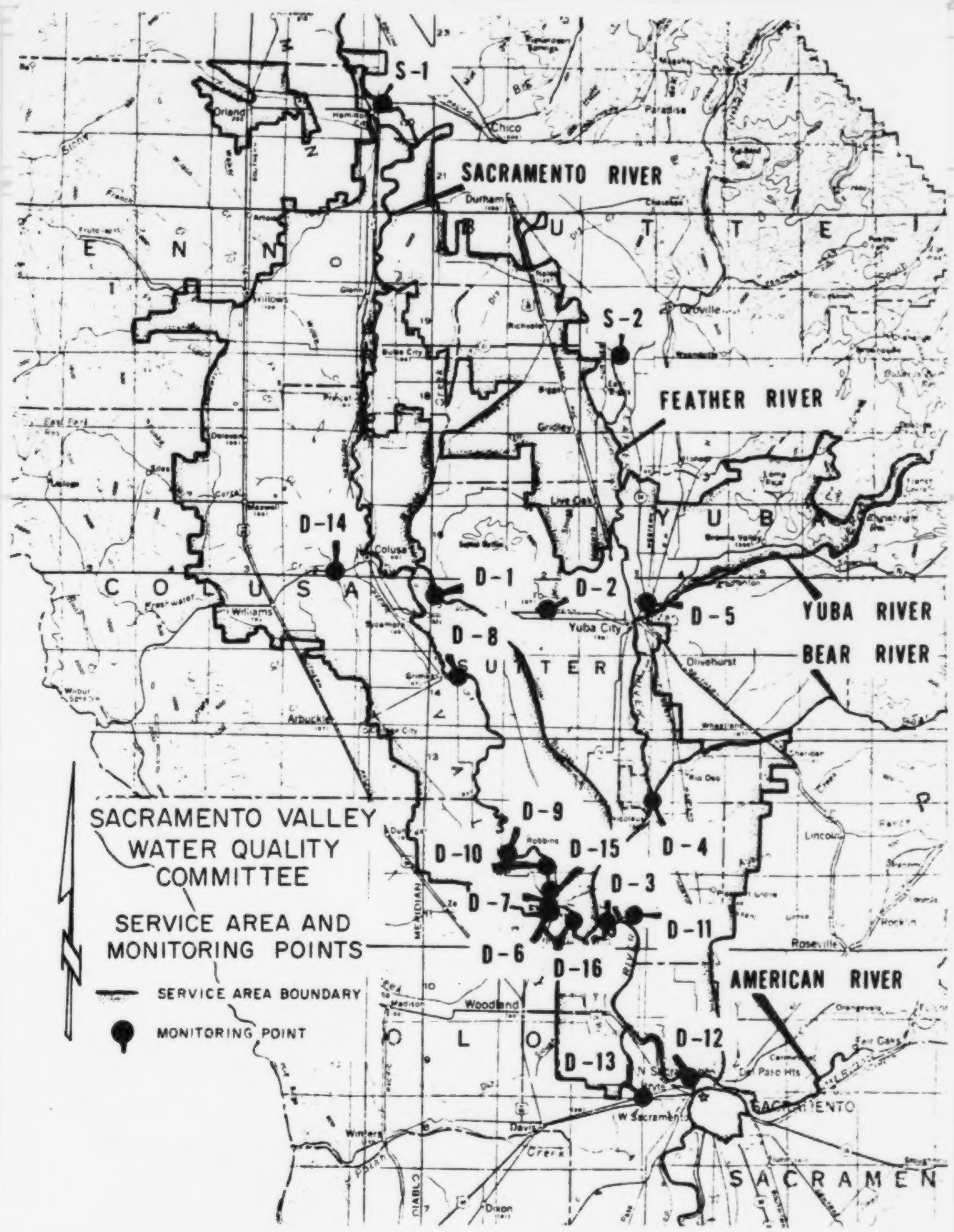
The following criteria were used for the selection of specific field study areas:

1. It should be representative of California irrigated agriculture.
2. It should have significant amounts of tailwater produced.
3. It should involve a large area having complex water use and management operations.
4. It should be in an area where irrigators and water districts are willing to collaborate and actively participate in the project.

GENERAL DESCRIPTION OF STUDY AREAS

Figure 3 shows the area for which an NPDES permit was acquired by the Sacramento Valley Water Quality Committee. The major supply water for this area is mainly diversions from streams in the Sacramento River system. Return flows are discharged back into the river system usually at some downstream location. The 1975-77 permit required monthly monitoring for water flow, electrical conductivity (EC), and suspended solids (SS) from 16 major surface diversions, one of which is the Colusa Basin Drain (D-16) as well as quarterly monitoring of two supply points, one of which is the Sacramento River at Hamilton City (S-1) that happens to be the main diversion point for Glenn-Colusa Irrigation District (GCID).

The Colusa Basin Drain (CBD) built about 1918-19 (Figure 4), conveys flood runoffs and irrigation return flows from about 4.05×10^3 km^2 (1 million ac) of upland watershed and valley floor agricultural levels in the west side of the Sacramento Valley. Flows during the nonirrigation season (November


S-1
S-2
SACRAMENTO RIVER
FEATHER RIVER
YUBA RIVER
BEAR RIVER
AMERICAN RIVER
G L E N N
B U T T E
Y U B A
C O L U S A
S U T T E R
Y O L O
S A C R A M E N
D-1
D-2
D-3
D-4
D-5
D-6
D-7
D-8
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D-10
D-11
D-12
D-13
D-14
D-15
D-16
Chico
Durham
Orland
Oroville
Gridley
Live Oak
Yuba City
Colusa
Williams
Arbuckle
Grimes
Olivehurst
Woodland
Davis
Winters
Dixon
W Sacramento
Del Paso Hts
Fair Oaks
Roseville
Lincoln
SACRAMENTO
SACRAMENTO VALLEY WATER QUALITY COMMITTEE
SERVICE AREA AND MONITORING POINTS
SERVICE AREA BOUNDARY
MONITORING POINT

Figure 3. NPDES permit area and monitoring points for the Sacramento Valley Water Quality Committee.

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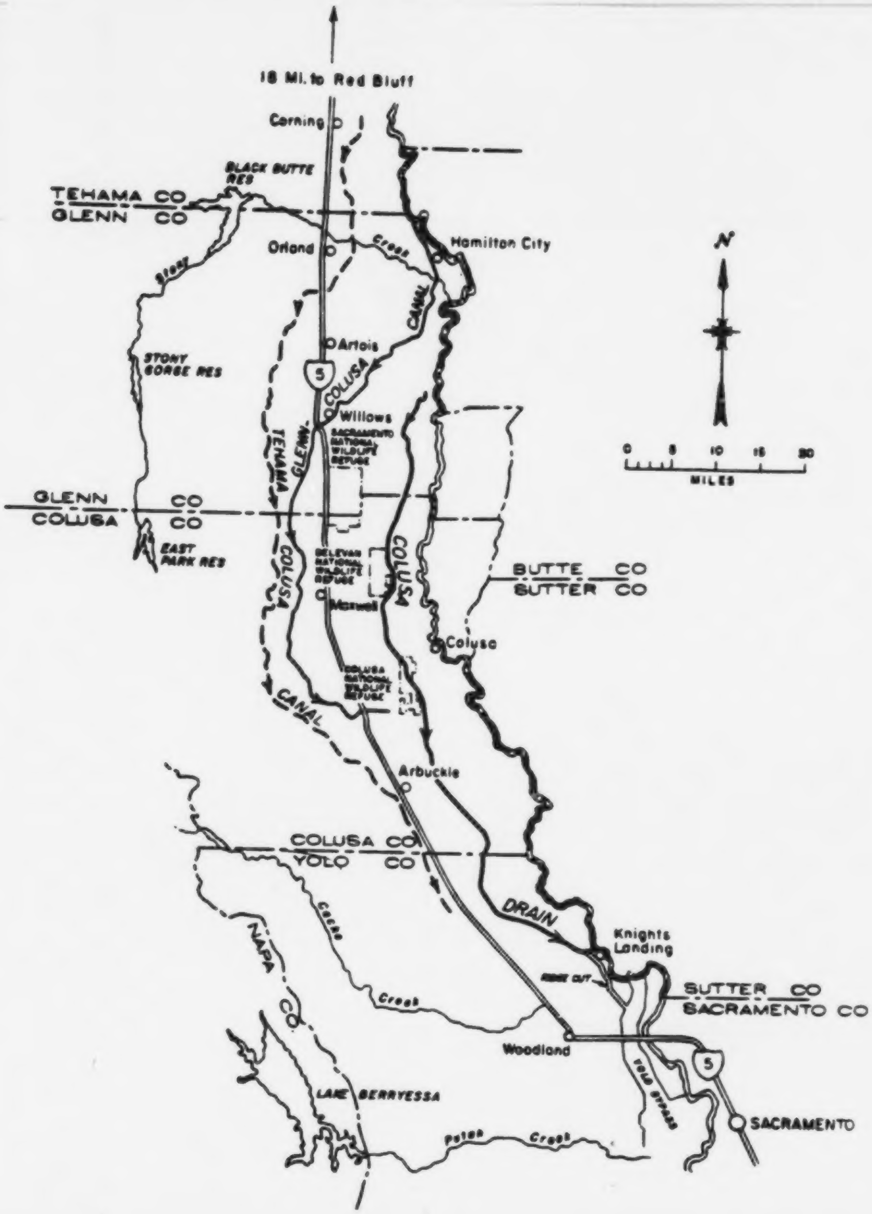
18 Mi. to Red Bluff
Corning
BLACK BUTTE RES
TEHAMA CO
GLENN CO
Orland
Stony
Creek
Hamilton City
N
CANAL
Artois
STONY GORGE RES
5
COLUSA
Willows
SACRAMENTO NATIONAL WILDLIFE REFUGE
GLENN
TEHAMA
0
5
10
15
20
MILES
GLENN CO
COLUSA CO
EAST PARK RES
DELEVAN NATIONAL WILDLIFE REFUGE
COLUSA
COLUSA
BUTTE CO
SUTTER CO
Maxwell
Colusa
COLUSA NATIONAL WILDLIFE REFUGE
CANAL
Arbuckle
COLUSA CO
YOLO CO
Cache
DRAIN
Knights Landing
NAPA CO.
RIDGE CUT
SUTTER CO
SACRAMENTO CO
Creek
Woodland
5
Yolo Bypass
LAKE BERRYESSA
SACRAMENTO
Putah
Creek

Figure 4. Location map of the Colusa Basin Drain in the west side of the Sacramento Valley.

through March) are quite variable, depending on the intensity and duration of storm events. The maximum rate of flow in the drain channel is about 244 m^3/s (8,600 cfs). Typically, winter flood runoffs are up to about 57 m^3/s (2,000 cfs) or greater and summer irrigation return flows between 14 m^3/s (500 cfs) and 42 m^3/s (1,500 cfs). A portion of the drain water in CBD is

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discharged into the Sacramento River near Knights Landing (Figure 4) and the remainder into Yolo Bypass via the Knights Landing Ridge Cut. These drain waters are extensively reused within the reaches of CBD as well as in Yolo Bypass.

The climate in the Sacramento Valley project area is characterized by cool, wet winters and hot, dry summers. The mean annual precipitation in the valley floor varies from 356 mm (14 in) to 508 mm (20 in) with 90% occurring between October and April. The growing season ranges from about 224 to 288 days. About 1,416 km^2 (350,000 ac) of the croplands are irrigated, with paddy rice the dominant crop (about 38% of the total). Pastures, hay crops, and orchards are usually irrigated by the basin or border method. Row crops such as corn, tomatoes, and sugar beets are furrow irrigated. Sprinkler irrigation is not widely practiced. The basin soils are fine-textured, comparatively impervious, and may be salt-affected to varying degrees. Soils in the alluvial fans and flood plains are mainly medium-textured with little or no profile development while soils in the older alluvial plains and terraces are generally finer-textured with dense, compacted subsoils. Coarse-textured materials are found along the present and old stream beds.

Large-scale diversions of Sacramento River water for irrigated agriculture was not started until about 1906. The Central Irrigation District was organized in 1887 for over 607 km^2 (150,000 ac) in the present Colusa and Glenn Counties. The district main canal and a pumping plant on the Sacramento River near Hamilton City (Figure 4) was completed in 1906. From this original district, six new districts were re-formed between 1916 and 1920. The largest of these being the present Glenn-Colusa Irrigation District (GCID) which now serves about 526 km^2 (130,000 ac). Specific information on GCID will be given later in Section 6.

Figure 5 shows the other study area, located in the west side of the San Joaquin Valley. On July 1975 the Mendota-Crows Landing Return Flow Group obtained an NPDES permit to discharge return flows from a 1.619×10^3 km^2 (400,000 ac) area representing 17 water and drainage districts, canal companies, wildlife and grassland areas and individual landowners. This group discharges its return flows into the middle reaches of the San Joaquin River through Salt Slough (D-1), Mud Slough North (D-2), and Oristimba Creek (D-3). The direction of drainage flow is easterly from the alluvial fans and then northerly in the basin rim and basin (Dickey, 1972). The permit required the reporting of water flows, EC, and SS during the irrigation season on a weekly basis for drain waters and on a monthly basis for the supply waters, monitored at the head of Arroyo Canal (S-1) and in the Delta-Mendota Canal at the Firebaugh Wasteway (S-2). Monitoring stations labelled with a prefix "I" are internal stations established by this project. In addition, three entities more closely studied were Broadview Water District which has no surface return flow discharges, Panoche Water District which uses some of the return flows but much of it is discharged into the Grasslands Water District where extensive reuse is made, and the Los Banos Wildlife Area which relies heavily on return flows as a source of water supply. More details will be given later for these units in Section 6.

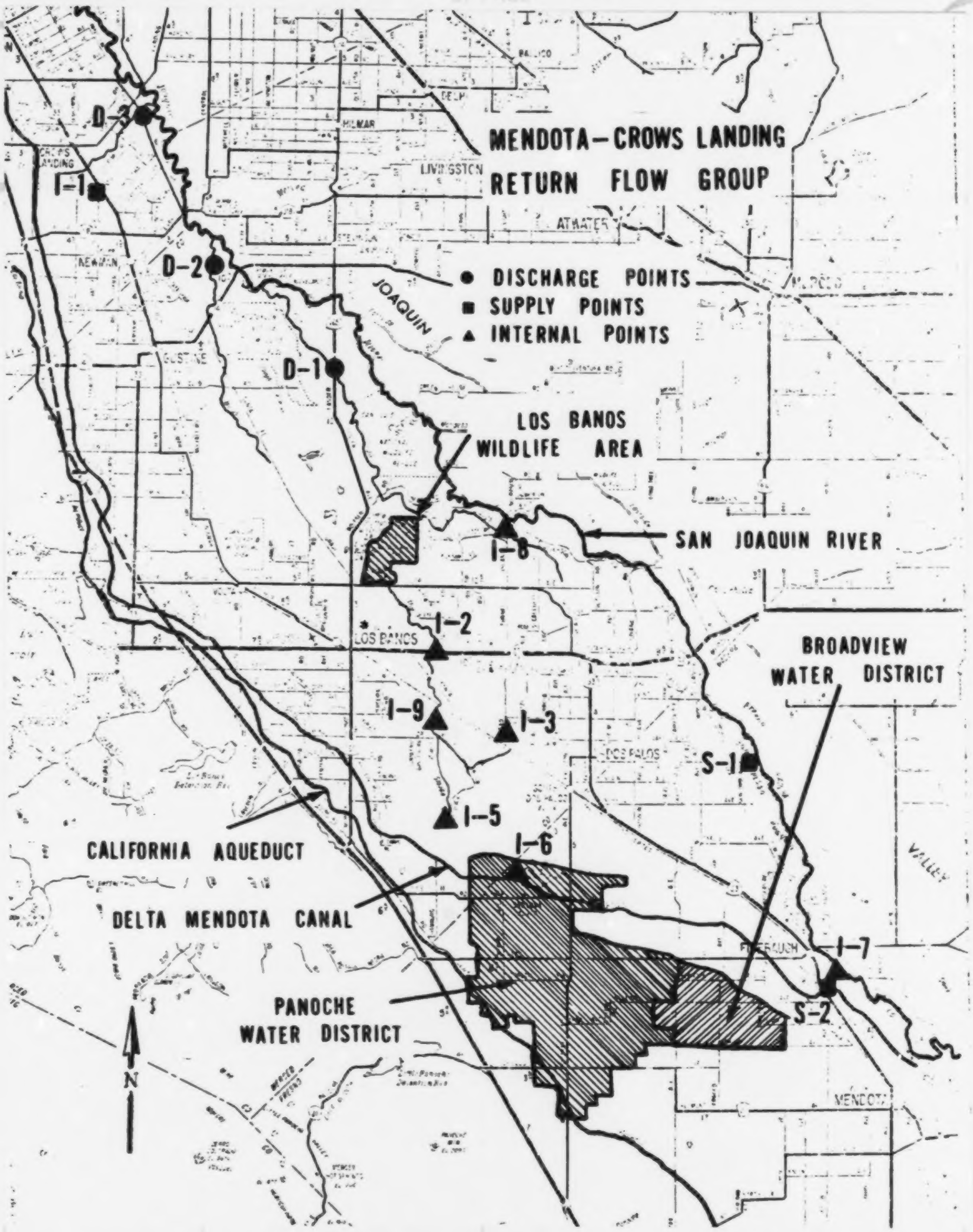
MENDOTA-CROWS LANDING
RETURN FLOW GROUP
● DISCHARGE POINTS
■ SUPPLY POINTS
▲ INTERNAL POINTS
D-3
I-1
D-2
D-1
LOS BANOS WILDLIFE AREA
SAN JOAQUIN RIVER
I-8
I-2
BROADVIEW WATER DISTRICT
I-9
I-3
S-1
I-5
I-6
CALIFORNIA AQUEDUCT
DELTA MENDOTA CANAL
I-7
S-2
PANOCHE WATER DISTRICT
N
HILMAR
DELHI
LIVINGSTON
ATWATER
MERCED
CROWS LANDING
NEWMAN
GUSTINE
JOAQUIN
LOS BANOS
DOS PALOS
FIREBAUGH
MENDOTA
VALLEY

Figure 5. NPDES permit area and monitoring points for the Mendota-Crows Landing Return Flow Group in the San Joaquin Valley.

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This study area has been under irrigation since the 1870's with the major supply source being water diverted from the middle reaches of the San Joaquin River in the vicinity of the present Mendota Pool southeast of Mendota. In July 1939, the U.S. Bureau of Reclamation (USBR) and the Miller and Lux and its subsidiary canal companies entered into a contract whereby USBR would build the Delta-Mendota Canal to import water from the Sacramento River Basin in exchange for the San Joaquin River water that would be diverted for use in the east side of the valley through the Friant-Kern Canal. This and other developments such as the construction of Shasta Dam are part of the USBR Central Valley Project. Because of the above contractural agreement there is no summer freshwater flow in the middle reaches of the San Joaquin River and would be otherwise dry if not for the discharges of return flows from surrounding irrigated lands. The Delta-Mendota Canal was built in 1951 and has an initial flow capacity of 130 m^3/s (4,600 cfs) in a channel that is partly concrete-lined and partly earth-lined. It extends 188 km (117 miles) from the Tracy Pumping Plant to the Mendota Pool. Water is delivered initially to the Mendota Pool and then distributed in a northeasterly direction by several canals. More recently, additional water is being imported from the Sacramento River Basin through the joint state-federal California Aqueduct (San Luis Aqueduct in the upper reaches) that runs parallel to Interstate 5.

The Mendota-Crows Landing Return Flow Group area receives a mean annual precipitation of about 178 mm (7 in) but may range from as low as 51 mm (2 in) to as high as 305 mm (12 in). Most of the rainfall occurs from November through April and the summers are dry and hot. The growing season in this area ranges from 288 to 323 frost free days. The soils along the western edge in this area are formed in place from sedimentary rocks, mostly sandstone and shale. The upper portions of the alluvial fans are well drained and generally are not salt-affected. The lower alluvial fans as well as the basin are salt-affected to varying degrees and is subject to water logging. The source of salinity in the soils is from the marine sedimentary rocks in the Coast Range Mountains that contain high concentrations of sodium, gypsum, and boron. The basin and lower fans are subject to high water table conditions due to seepages from upslope irrigated lands and the river system.

The land use of this area was initially grazing and beef production and dry land grain farming. With the development of the Miller and Lux Canal system, pastures were irrigated and hay and grain production were increased. As alfalfa production became possible a dairy industry developed. Up to the time of construction of the Delta-Mendota Canal much of the agriculture was devoted to dairying and feed production. This was later followed by orchards (walnuts, almonds, peaches) in the central western portion and row crops (cotton, sugar beets, tomatoes, melons, etc.). Small grain production in the winter is still significant and now rice is being grown on the more impermeable basin soils. A large fraction of the land (542 km^2 or 133,950 ac) is still being devoted to permanent irrigated pastures and wildlife habitat, mainly migratory birds on the Pacific Flyway. Thus, there are two distinct land uses represented in this study area. They are the areas that are extensively cropped, producing surface and subsurface return flows while other areas are devoted to native pastures and wildlife that utilize the return flows from irrigated lands.

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SECTION 6

RESULTS AND DISCUSSION

NPDES AND INTERNAL MONITORING STATIONS

The results and appraisals in the NPDES permit areas in the Sacramento and San Joaquin Valley study sites will be first presented. This will be followed by more comprehensive district and on-farm type of studies. Since it will not be possible to completely present the collected information and data base, the reader is referred to the 1975-76 (Tanji et al., 1976) and 1976-77 (Tanji et al., 1977) annual reports.

Colusa Basin Drain

As stated earlier the 113 km (70 mile) Colusa Basin Drain (CBD) is a major drainage facility in the west side of the Sacramento Valley. Figure 6 shows the location of the five monitoring stations on CBD along with the supply water diversion point near Hamilton City for Glenn-Colusa Irrigation District (GCID). Data for the latter will be reported along with those from CBD to illustrate water quality differences. The inset to Figure 6 shows some details of the outfall of CBD into the Sacramento River near Knights Landing (NPDES Station D-6 in Figure 3). The return flows during the irrigation season and flood runoffs are passed through the outfall gates as well as into the Yolo Bypass via the Knights Landing Ridge Cut. The outfall gates are closed when the water stage height in the Sacramento River is higher than the drain. This occurs during heavy storm runoffs and large reservoir releases upstream in the Sacramento River, normally from December through March. Water quality samples were taken at weekly intervals at CBD-1, the drain outflow station, and at monthly intervals at other stations. CBD-3 is the only station equipped with stream gauging. For other stations, estimates of water flow were obtained by the current velocity-cross sectional area method.

Table 1 gives the seasonal water quality in several reaches of the CBD and supply water for GCID (Figure 6), i.e., the Sacramento River water. The water quality is characterized by the salinity parameters, EC and TDS, as well as suspended matter parameters, turbidity and SS. EC and turbidity are intensive parameters while TDS and SS are extensive parameters. The GCID supply water contains very low salinity and suspended matter. EC and TDS in CBD tend to increase with downstream travel for both the irrigation and nonirrigation seasons. This increase in salts during the irrigation season is mainly due to the concentrating effects of evapotranspiration as drain waters are consumptively used for irrigation and other uses and the

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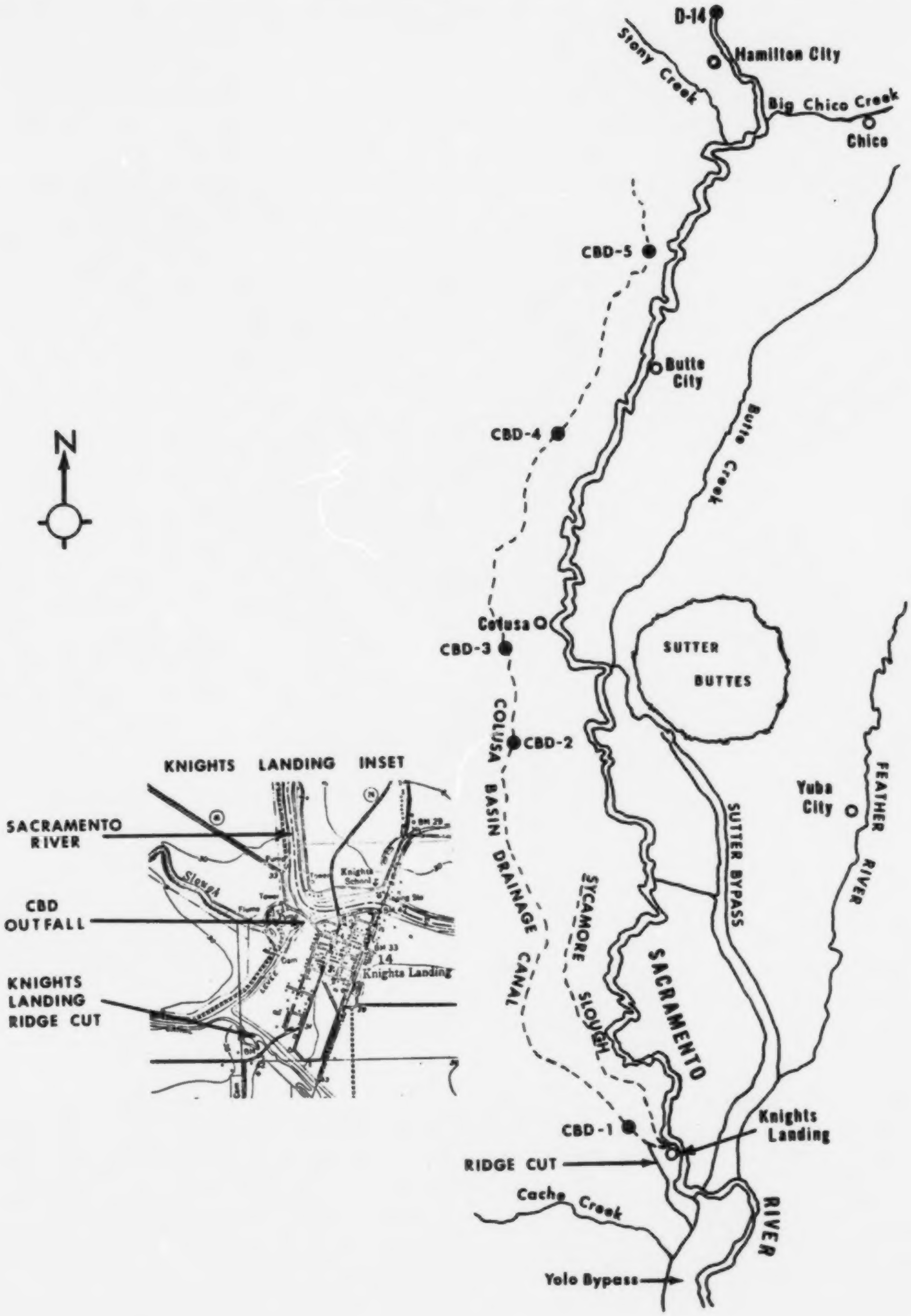
D-14
Hamilton City
Stony Creek
Big Chico Creek
Chico
CBD-5
Butte City
CBD-4
Butte Creek
N
Colusa
CBD-3
SUTTER BUTTES
COLUSA BASIN DRAINAGE CANAL
CBD-2
KNIGHTS LANDING INSET
SACRAMENTO RIVER
CBD OUTFALL
KNIGHTS LANDING RIDGE CUT
Knights Landing
Yuba City
FEATHER RIVER
SUTTER BYPASS
SYCAMORE SLOUGH
SACRAMENTO
CBD-1
Knights Landing
RIDGE CUT
Cache Creek
RIVER
Yolo Bypass

Figure 6. Monitoring stations in the Colusa Basin Drain.

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TABLE 1. THE 1975-77 SEASONAL WATER QUALITY IN THE COLUSA BASIN DRAIN

Stations	Description	Seasons[*]		EC[†] (mS/cm)	TDS[‡] (mg/ℓ)	Turbidity[§] (JTU)	SS[#] (mg/ℓ)
D-14	GCID Supply Water	1975	Irrigation Season	.180	116	15	24
		1976	Irrigation Season	.133	97	8	12
		1975-76	Nonirrigation Season	-	-	-	-
		1976-77	Nonirrigation Season	-	-	-	-
CBD-5 (D-5)	CBD at Sidds Road	1975	Irrigation Season	.315	187	16	31
		1976	Irrigation Season	.322	197	21	48
		1975-76	Nonirrigation Season	.393	241	9	15
		1976-77	Nonirrigation Season	.418	226	78	77
CBD-4 (D-15)	CBD at Princeton Road	1975	Irrigation Season	.409	243	22	48
		1976	Irrigation Season	.375	230	17	31
		1975-76	Nonirrigation Season	.394	239	31	42
		1976-77	Nonirrigation Season	.456	271	260	225
CBD-3 (D-12)	CBD at Colusa Bridge, Hwy 20	1975	Irrigation Season	.603	362	37	74
		1976	Irrigation Season	.601	367	44	88
		1975-76	Nonirrigation Season	.720	439	53	74
		1976-77	Nonirrigation Season	.893	533	111	130
CBD-2	CBD at Davis Weir	1975	Irrigation Season	.651	379	46	78
		1976	Irrigation Season	.634	385	35	57
		1975-76	Nonirrigation Season	.701	430	43	64
		1976-77	Nonirrigation Season	.843	516	119	122
CBD-1	CBD at Roads 99E and 108	1975	Irrigation Season	.721	427	66	111
		1976	Irrigation Season	.613	373	53	76
		1975-76	Nonirrigation Season	.814	496	44	55
		1976-77	Nonirrigation Season	.854	514	33	36

[*] Irrigation season is April through October and nonirrigation season is November through March.

[†] Electrical conductivity in milliSiemen per centimeter (mS/cm = 1000 micromhos/cm).

[‡] Total dissolved solids.

[§] Turbidity in Jackson Turbidity Units.

[#] Suspended Solids.

return flows are discharged back into the drain. During the nonirrigation season, EC and TDS also increase mainly due to the chemical weathering and leaching of salts from the watershed and valley floor soils. Note that salinity is generally higher during the winter runoff. The trends in turbidity and SS are similar to that of salinity during the irrigation season, and are highly variable in the nonirrigation season. The variability in suspended matter in CBD reflects differences in soil erodibility and sediment production in the drainage subareas as well as relative differences in the rates of sediment deposition and sediment resuspension for various reaches in the CBD. Note that suspended matter is generally greater in the nonirrigation than in the irrigation season, similar to salinity. During the irrigation seasons EC at CBD-1 is about 4.3 times that of GCID supply water while SS at CBD-1 is about 5.2 times that of the supply water. Although these relative increases are large the overall quality of the drain waters discharged from CBD is considered to be good quality irrigation water.

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The seasonal average data given in Table 1 was obtained from monthly records. For illustrative purposes, Figures 7 and 8 respectively show the 1975-77 EC and SS values for the GCID supply water (D-14), middle reach of the drain (CBD-3), and the outflow station for the drain (CBD-1). Within a given season, some fluctuations in EC and SS are noted. EC's are lowest in March through April and highest in December through January. Peak concentration of SS occurred in September, 1975 and January, 1977.

Table 2 gives the monthly flows of water and mass of TDS and SS discharged from the CBD as monitored at CBD-1. During the irrigation seasons the peak discharges of water, TDS, and SS occurred in September when the flooded rice fields are drained in preparation for harvesting. In the non-irrigation season, during the study period of this project, flows of water, TDS, and SS were smaller than in the irrigation season. Normally, it is just the reverse of this; the reason for the reversal is attributed to record drought during the 1975-77 period. Taking irrigated croplands to be 1,417 km^2 (350,000 ac), the average unit mass emission rate for water, TDS, and SS during the irrigation season are, respectively, 169 m^3/km^2 (0.55 ac-ft/ac), 60.5 tons/km^2 (540 lbs/ac), and 18.1 tons/km^2 (162 lbs/ac). Taking total land area drained during storm runoffs to be 4,047 km^2 (1,000,000 ac), the average unit mass emission rate for water, TDS, and SS during the nonirrigation season are respectively, 16 m^3/km^2 (0.05 ac-ft/ac), 7.6 tons/km^2 (68 lbs/ac), and 0.9 tons/km^2 (8 lbs/ac). These unit mass emission rates, except for water during the irrigation season, are considered to be very low.

Mendota-Crows Landing Return Flow Group

The monitoring stations for the 1,619 km^2 (400,000 ac) Mendota-Crows Landing Return Flow Group (MCLRFG) was previously given in Figure 5. Unlike the Sacramento Valley NPDES permittee, this group receives imported water, mainly through the Delta-Mendota Canal, and discharges its return flow into the middle reaches of the San Joaquin River from Salt Slough (D-1), Mud Slough North (D-2) and Orestimba Creek (D-3).

Table 3 presents the 1975-77 seasonal water quality for the NPDES permit. Because of the longer growing season than in the Sacramento study site, double cropping is practiced to some extent. Summer crops are usually planted in March and April and winter crops in late fall. The irrigation season in this area may commence as early as January or as late as April, and may terminate as early as October or extend into December, depending upon winter rainfall and the need to rennovate the supply distribution system, usually in November and December. Thus the data in Table 3 are grouped into time periods that approximately corresponds to the aforementioned conditions as well as constraints in the starting (March, 1975) and ending (March, 1977) dates for this project. It should be mentioned that the NPDES permit was officially granted in July 1975 but monitoring, with the cooperation of the return flow group, was begun in May 1975.

The quality of supply water for the MCLRFG is more saline and more turbid than that of GCID's and approaches that of the drain waters in CBD (Table 1). The flow data presented does not represent the total supply water for this area because they do not include other sources such as the California

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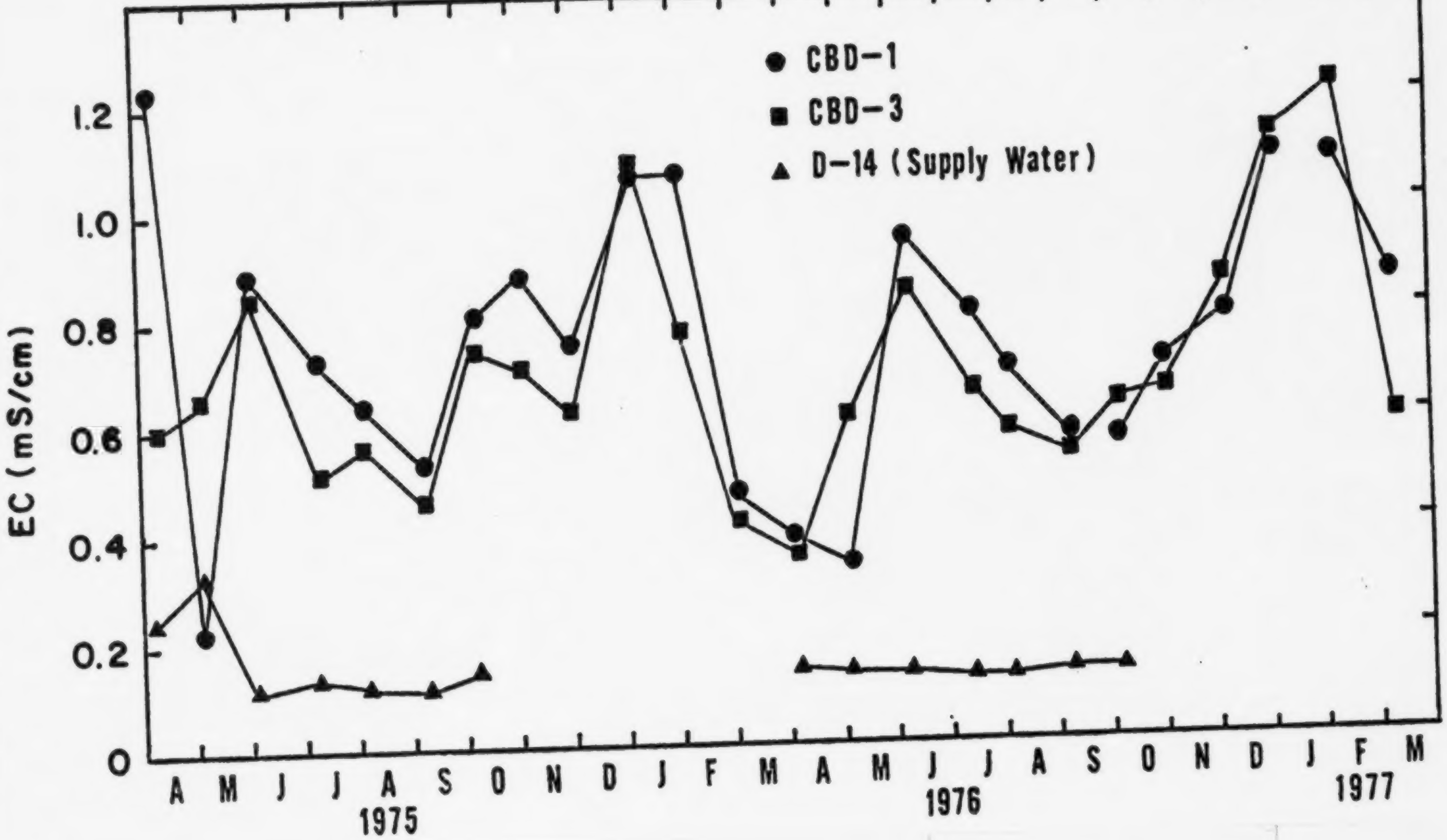

Figure 7. Monthly EC of supply water and middle and lower reaches in the Colusa Basin Drain.

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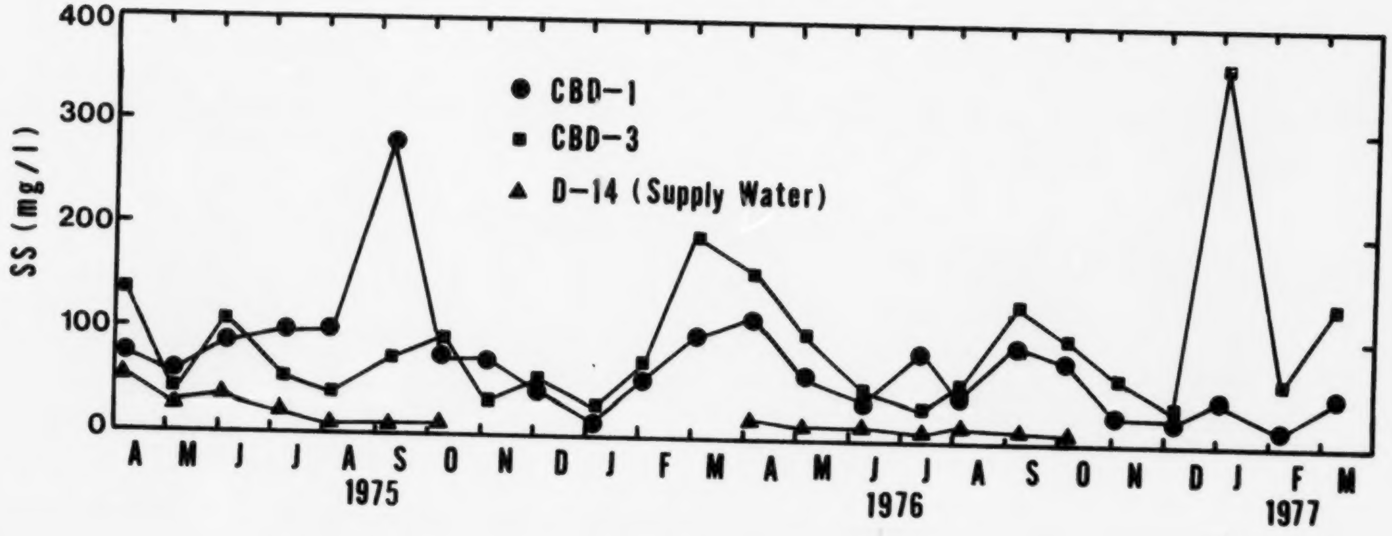

Figure 8. Monthly SS of supply water and middle and lower reaches in the Colusa Basin Drain.

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TABLE 2. MONTHLY WATER FLOWS, SALINITY, AND SUSPENDED SOLIDS AT THE CBD-1 IN THE COLUSA BASIN DRAIN, 1975-1977

IRRIGATION SEASON					NONIRRIGATION SEASON				
Month and year		Flow ($10^6 m^3$)	TDS (tons)	SS (tons)	Month and year		Flow ($10^6 m^3$)	TDS (tons)	SS (tons)
April	1975	9.8	3,543	1,250	November	1975-76	22.3	9,393	1,469
	1976	16.1	5,729	1,324		1976-77	10.7	5,977	440
May	1975	31.5	11,335	3,999	December	1975-76	22.0	9,268	1,450
	1976	36.2	12,860	2,971		1976-77	1.5	855	63
June	1975	14.0	5,041	1,778	January	1975-76	7.3	3,066	480
	1976	2.4	841	194		1976-77	21.9	12,205	898
July	1975	38.6	13,904	4,905	February	1975-76	3.2	1,364	213
	1976	8.6	3,053	705		1976-77	11.1	6,162	454
August	1975	70.8	25,476	8,987	March	1975-76	20.4	8,596	1,344
	1976	67.7	24,041	5,553		1976-77	8.9	4,948	364
September	1975	84.6	30,465	10,747					
	1976	71.4	25,347	5,855					
October	1975	17.8	6,423	2,266					
	1976	9.3	3,299	762					
Total	1975	267.1	96,187	33,933	Total	1975-76	75.1	31,687	4,956
	1976	211.7	75,169	17,363		1976-77	54.1	30,147	2,219

Table 3. The 1975-77 seasonal water quality in the NPDES monitoring stations[*] in the Mendota-Crows Landing Return Flow Group.

Station	Description	Dates	Flow $(10^6 m^3)$	EC (mS/cm)	TDS (mg/ℓ)	Turbidity (JTU)	SS (mg/ℓ)	B[†] (mg/ℓ)
Supply Water:								
S-1	Arroyo Canal	5/75-10/75	161.8	0.502	278	33	118	0.2
		11/75-3/76	30.9	0.579	346	18	26	0.2
		4/76-10/76	185.9	0.548	331	43	91	0.2
		11/76-3/77	25.7	1.125	631	20	28	0.2
S-2	Delta-Mendota Canal	5/75-10/75	978.9	0.468	205	41	107	0.2
		11/75-3/76	227.6	0.806	474	21	35	0.3
		4/76-10/76	1,034.9	0.474	279	41	78	0.2
		11/76-3/77	167.5	0.948	533	16	22	0.2
Drainage Water:								
D-1	Salt Slough	5/75-10/75	56.8	1.462	821	35	91	0.6
		11/75-3/76	37.7	2.294	1,590	22	34	1.4
		4/76-10/76	63.9	1.399	808	46	105	0.4
		11/76-3/77	36.3	2.731	1,710	21	41	1.8
D-2	Mud Slough North	5/75-10/75	6.3	1.933	1,210	56	97	1.6
		11/75-3/76	42.1	2.824	1,890	33	58	2.7
		4/76-10/76	16.5	1.617	980	51	69	1.2
		11/76-3/77	35.1	2.507	1,205	31	32	1.9
D-3	Orestimba Creek	5/75-10/75	9.3	0.621	374	305	572	0.2
		11/75-3/76	2.0	0.992	619	22	30	0.4
		4/76-10/76	12.6	0.683	394	212	306	0.3
		11/76-3/77	1.3	1.468	891	15	19	0.6

[*] See Figure 5 for locations.

[†] Boron.

Aqueduct, pumped ground water, and capture and reuse of return flows from the east side of the San Joaquin Valley. Moreover, the return flows generated within the study area are used a number of times prior to final discharge into the San Joaquin River.

Table 3 also contains flow and water quality data for the NPDES discharge stations. Station D-3 is different from the other two in that EC is lower because part of the flow is comprised of operational spills. The SS is however higher because of steeper gradient in the channel of Orestimba Creek and steeper, highly erodible slopes in the drainage area. Stations D-1 and D-2 are the main discharge points for the MCLRFG. Salinity is usually greater during late fall and winter because the return flows are composed

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mainly of subsurface drainage that is more saline and less turbid than surface sources of return flows. The EC's of the return flows are substantially increased over that of the supply water and they contain appreciable concentrations of boron leached from the salt-affected soils in this area. Drainage for much of the MCLRFG is subdivided by the Santa Fe Grade that runs parallel to the Delta-Mendota Canal. Salt Slough (D-1) drains the portion east of this grade while Mud Slough North (D-2) drains the portion west of this grade. However, when viewed in smaller subareas, the drainage network is much more complex (Dickey, 1972). In addition to the slower current velocities in Salt Slough and Mud Slough North, the suspended load is smaller since a significant amount of the sediments in the return flows is deposited in the grassland and wildlife areas, where reuse takes place.

Figures 9 and 10 contain plots of water flow, EC, and SS for the supply station S-2) and discharge station D-1 at monthly and weekly intervals, respectively. The peak flows in S-2 occurred from June through August. In contrast, the peak flows in D-1 occurred from mid-August to early September for both years. Some of the contributing factors to the lag time noted between water delivery and discharge are travel time through soils and collection as return flows in canals, the reuse and discharge of waters from the wildlife and grassland areas, and the drainage of rice fields prior to harvest. In addition, high flows in D-1 also occurred as in February and March of 1976, most probably due to the discharge of water from duck ponds. Similar discharges did not occur in 1977 because of drought. The ECs of supply water were generally low, except for certain periods such as August 1975, January and February of 1976 and 1977 and October of 1976. They reflect for the most part sea water intrusion into the Delta during low summer and fall flows from the Sacramento and San Joaquin River systems. The ECs were abnormally high in the winters of 1976 and 1977 because of record drought when there was little or no storm runoffs and upstream reservoir releases were drastically cut back. The 1975 irrigation season is considered to be representative of a normal hydrologic year while 1976 is the first of the two consecutive dry-year conditions in the Central Valley of California. But, since the water used in this area is primarily that which is imported, no significant impacts seemed to have occurred in 1976. This is not true for the 1977 irrigation season since project water was reduced back to only 25% of normal.

Table 4 presents more seasonal water quality data for the internal monitoring stations identified in Figure 5. The flow data are incomplete for several reasons, including the excessive high costs of installing flow measuring devices in certain channel configurations and the periodic reversal in the direction of water flows. Note that I-1, I-7, and I-8 in the drainage network also provided supply water to the low-lying croplands, grasslands, and wildlife refuges. These waters are about two to three times as saline as the fresh canal water. Other more saline high boron waters (I-3, I-5, I-6, I-9) are discharged into Salt Slough and Mud Slough North or their tributaries, and reused in pastures and wildlife habitats before final discharge into the main drains. Note that the salinity in these drains is about six to eight times greater than in S-2 and boron ranges from 1.1 to 7.1 mg/l.

Although the NPDES supply and discharge stations presumably include the major supply and discharge waters in the MCLRFG, they do not appear to

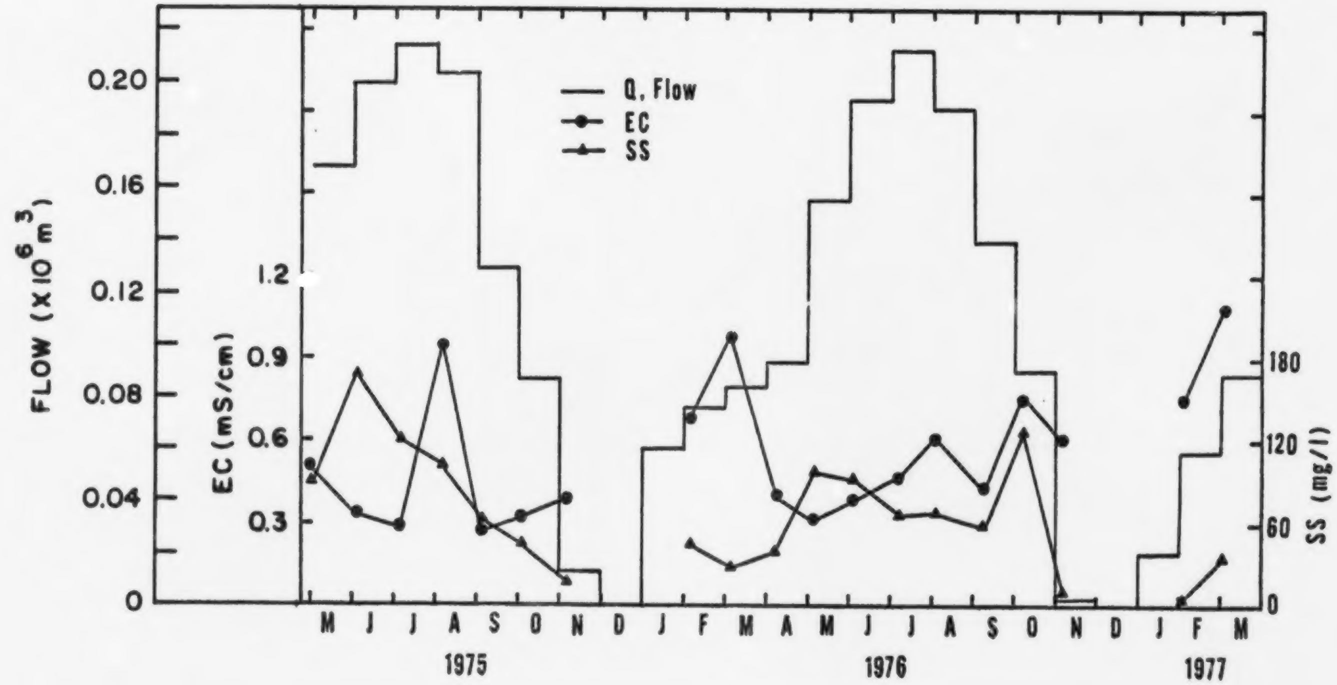

Figure 9. Monthly flow, EC, and SS in the supply station S-2 in the Mendota-Crows Landing Return Flow Group.

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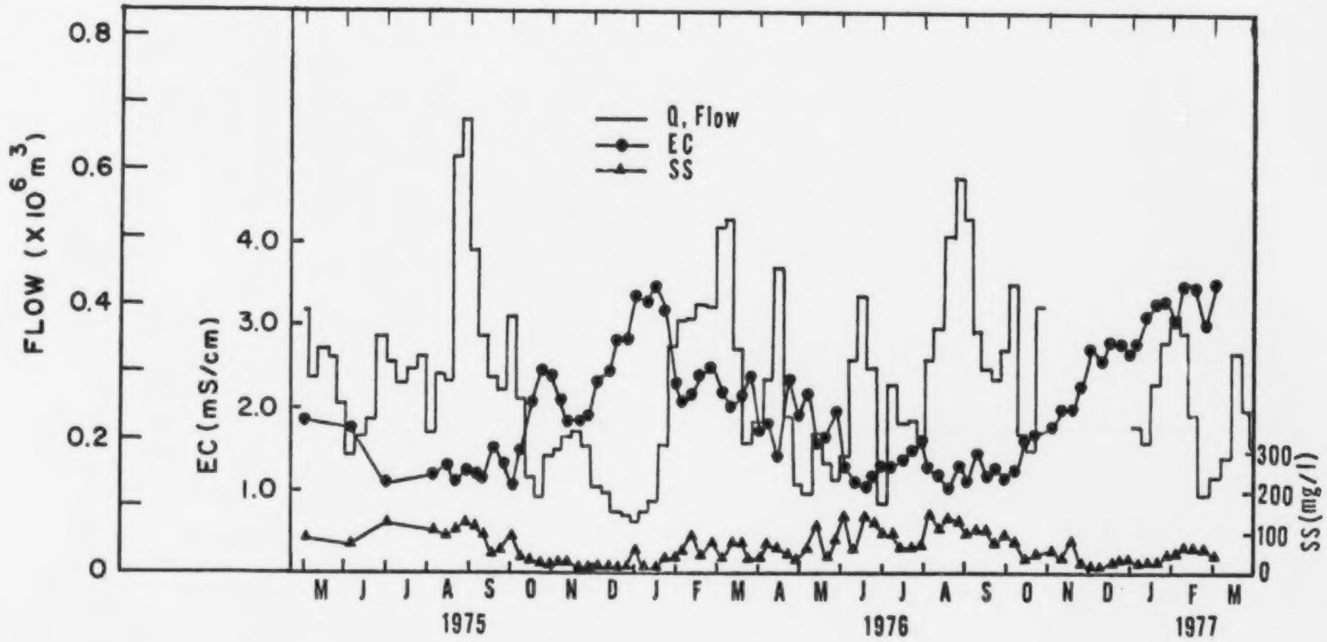

Figure 10. Weekly flow, EC and SS in the discharge station D-1 in the Mendota-Crows Landing Return Flow Group.

Table 4. The 1975-77 seasonal water quality in the internal discharge monitoring stations* in the Mendota-Crows Landing Return Flow Group.

Station	Description	Dates	Flow ($10^6 m^3$)	EC (mS/cm)	TDS (mg/ℓ)	Turbidity (JTU)	SS (mg/ℓ)	B (mg/ℓ)
I-1	GCID Main Canal*	5/75-10/75	-	0.878	507	35	63	0.5
		11/75-3/76	8.3	0.961	583	26	39	0.4
		4/76-10/76	77.5	0.771	447	77	131	0.5
		11/76-3/77	6.9	1.632	995	30	61	0.8
I-2	Mud Slough South	5/75-10/75	-	2.085	1,340	37	83	2.6
		11/75-2/76	-	2.663	1,840	18	27	3.2
I-3	Bennet Drain	5/75-10/75	-	2.977	1,800	32	73	1.2
		11/75-3/76	-	2.713	1,820	31	48	2.6
		4/76-10/76	2.1	2.621	1,650	32	54	1.1
		11/76-3/77	0.3	3.922	2,630	25	36	2.9
I-5	Camp 13 Slough	5/75-10/75	-	3.008	1,990	90	258	4.2
		11/75-3/76	6.2	5.105	3,810	42	110	7.1
		4/76-10/76	15.7	3.569	2,530	168	286	3.9
		11/76-3/77	5.5	4.119	2,940	68	146	4.4
I-6	Panoche District Drain	5/75-10/75	24.0	3.070	2,050	126	348	4.8
		11/75-3/76	15.8	2.167	1,480	127	263	3.2
		4/76-10/76	24.5	3.058	2,100	208	308	5.1
		11/76-3/77	12.0	3.829	2,630	143	291	5.3
I-7	Firebaugh Wasteway*	5/75-10/75	-	0.929	567	53	121	0.6
		11/75-3/76	-	1.214	796	31	40	0.7
		4/76-10/76	-	1.632	1,060	50	86	1.3
		11/76-3/77	-	2.117	1,370	25	34	1.3
I-8	Turner Island Intake*	5/75-10/75	18.4	0.890	511	51	136	0.1
		11/75-3/76	5.2	0.962	585	36	71	0.2
		4/76-10/76	19.7	0.843	458	56	127	0.2
		11/76-3/77	3.4	1.318	253	27	48	0.1
I-9	Mud Slough below Geis Ditch	11/75-3/76	-	3.542	2,070	71	125	4.9
		4/76-10/76	29.4	3.286	2,280	75	142	5.2
		11/76-2/77	20.8	4.480	2,580	39	51	5.0

*Also supply source.

represent the total supply nor the total discharge. Thus, it is not possible to fully appraise the mass inflow and mass outflow of waters, salinity and suspended matter. Nevertheless, Table 5 presents existing data on discharge stations D-1, D-2, and D-3 for two periods, April, 1975 through March, 1976 and April, 1976 through March, 1977 that correspond to the first and second

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TABLE 5. MONTHLY WATER FLOWS, TDS, AND SS IN THE NPDES DISCHARGE STATIONS IN THE MENDOTA-CROWS LANDING RETURN FLOW GROUP

Month and Year		Station D-1			Station D-2			Station D-3		
		Flow ($10^6 m^3$)	TDS (m.tons)	SS (m.tons)	Flow ($10^6 m^3$)	TDS (m.tons)	SS (m.tons)	Flow ($10^6 m^3$)	TDS (m.tons)	SS (m.tons)
April	1975	-	-	-	-	-	-	-	-	-
	1976	8.1	6,700	765	2.5	2,488	146	1.6	721	423
May	1975	9.5	7,213	871	-	-	-	1.6	679	552
	1976	5.0	4,080	465	0.5	522	31	2.3	1,019	596
June	1975	7.4	5,658	683	-	-	-	1.7	732	596
	1976	9.1	7,507	856	0.1	102	6	1.4	598	350
July	1975	9.4	7,133	861	0.3	232	24	2.3	965	786
	1976	7.3	5,975	681	0.1	94	5	1.8	772	452
August	1975	14.2	10,784	1,302	0.7	578	60	1.7	732	596
	1976	14.2	11,722	1,337	0.5	451	26	2.1	904	529
September	1975	10.2	7,802	942	0.6	488	51	1.3	567	462
	1976	10.2	8,437	963	2.1	2,151	126	2.1	909	533
October	1975	6.1	4,669	563	4.8	4,188	434	0.6	258	210
	1976	10.0	8,243	941	10.7	10,798	632	1.4	591	347
November	1975	6.2	8,961	279	11.3	19,593	578	0.3	268	23
	1976	9.2	16,489	414	10.8	18,111	510	0.3	306	5
December	1975	3.2	4,632	144	4.3	7,425	219	0.1	100	8
	1976	4.1	7,272	182	2.3	3,779	106	0.9	864	15
January	1976	5.4	7,775	242	11.8	20,391	601	0.4	372	32
	1977	8.9	15,892	399	12.0	19,987	562	-	-	-
February	1976	11.3	16,273	507	9.8	17,022	502	0.2	214	18
	1977	7.2	12,869	323	8.3	13,829	389	-	-	-
March	1976	11.6	16,754	523	4.9	8,402	248	1.1	1,083	93
	1977	7.0	12,538	315	1.8	2,932	83	-	-	-
Total	4/75-3/76	94.5	97,654	6,917	(53.4)	(78,319)	(2,717)	11.3	5,970	3,376
	4/76-3/77	100.3	117,664	7,641	91.7	75,244	2,622	(13.9)	(6,684)	(3,250)

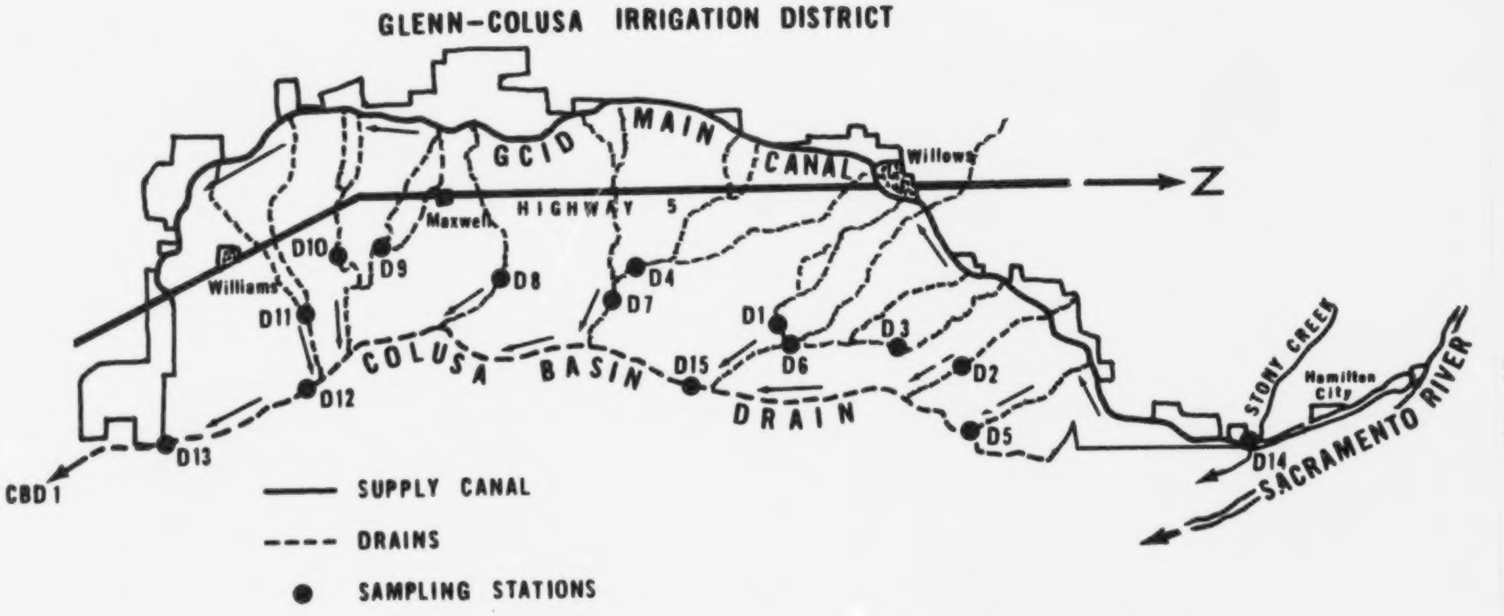
years of this project. As previously mentioned, D-3 drains a smaller area with comparatively smaller salt discharges but higher sediment discharges. In contrast, D-1 and D-2 drain large areas with comparatively higher salt discharges and smaller sediment discharges.

GLENN-COLUSA IRRIGATION DISTRICT

Glenn-Colusa Irrigation District (GCID) is the oldest (1887) and largest (662.5 km^2) irrigation district in the Sacramento Valley. Figure 11 contains a map of GCID with an outline of the main canal and lateral drains. This district is located in the northeastern portion of the Sacramento Valley NPDES permittee (Figure 3) and to the west of the Colusa Basin Drain (Figure 6), wherein GCID sampling stations D-5, D-15, and D-12 correspond respectively to CBD sampling stations CBD-5, CBD-4, and CBD-3. The soils along the creeks, which also serve as lateral drains, are coarser textured while soils in the basin and basin rim are finer textured, some of them sodium-affected. Recipitation occurs mainly in the winter with mean annual precipitation of about 460 mm (18 inches). The growing season is about 224 frost-free days. As shown in Table 6, paddy rice, which is more or less continually flooded throughout the growing season, is the dominant crop. This district also distributes water to duck ponds and wildlife refuge units operated by private duck and gun clubs as well as by the federally-operated Sacramento National Wildlife Refuge. Pastures, hay crops, and orchards are usually irrigated by the basin or border method. Row crops such as corn, tomatoes, and sugar beets are furrow irrigated. Only a small fraction of the irrigated lands are sprinkler irrigated. The irrigation season starts in April and ends in October.

GCID obtains its supply water by diversions from the Sacramento River near Hamilton City as well as from Stony Creek (Figure 11). This district has riparian water rights and purchases additional water from the USBR Central Valley Project amounting to about 10% of the total supply. The supply water is distributed by the 105 km (65 mile) main canal that has a 85 m^3/s (3,000 cfs) capacity and is located along the districts' western boundary. There are some 424 km (400 miles) of lateral distribution canals in an easterly to south easterly direction. All of these canals are unlined but with permanent concrete structures. Flow is by gravity. The district distribution system also involves capture of drain waters by either gravity or low lift pumps at 20 locations scattered throughout the district. Normally, one-half of the surface drain waters are reused within the district and the remainder is discharged into the upper reaches of the CBD from which further reuse is made by downstream irrigators. The district inflow monitoring station is at D-14 and the outflow station at D-13.

Figure 12 depicts the monthly flow, TDS, and SS for GCID during the 1975 and 1976 irrigation seasons. Unlike the MCLRFG, there is little or no lag time between delivery and discharge in GCID because of the shorter travel distances to the CBD along the lateral drains. The surface drain outflow normally has two peak flow periods. The first occurs in May when the flood waters in the rice fields are lowered to prevent erosion of levees during gusty north winds and oftentimes after the aerial application of herbicides. The second peak occurs late in the irrigation season when rice fields are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HIGHWAY 5
Maxwell
Williams
D1
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D10
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D12
D13
D14
D15
COLUSA BASIN DRAIN
STONY CREEK
Hamilton City
SACRAMENTO RIVER
CBD1
SUPPLY CANAL
DRAINS
SAMPLING STATIONS

Figure 11. Network of supply and drainage system and monitored stations in Glenn-Colusa Irrigation District.

TABLE 6. GLENN-COLUSA IRRIGATION DISTRICT SERVICE AREA IN THE 1975 AND 1976 IRRIGATION SEASONS

Description	Area (km^2)	
	1975	1976
GCID Water delivery;		
Rice	377.84	328.70
Tomatoes	4.07	4.18
Sugar beets	6.61	6.36
Clover	22.86	20.98
Alfalfa	7.47	8.75
Corn	7.87	25.17
Orchard	7.28	7.59
General field crops*	25.48	62.62
Duck ponds†	9.68	11.06
One irrigation‡	33.53	46.40
Two irrigations‡	8.60	18.27
Subtotal	511.29	540.08
Refuge water delivery:		
Rice	3.04	3.47
General field crops	9.31	8.78
Duck ponds	12.55	13.25
Subtotal	24.90	25.50
Grand total:	536.19	565.58

* Includes pasture, hay, and small grains

† Private duck clubs

‡ Crops irrigated only once or twice

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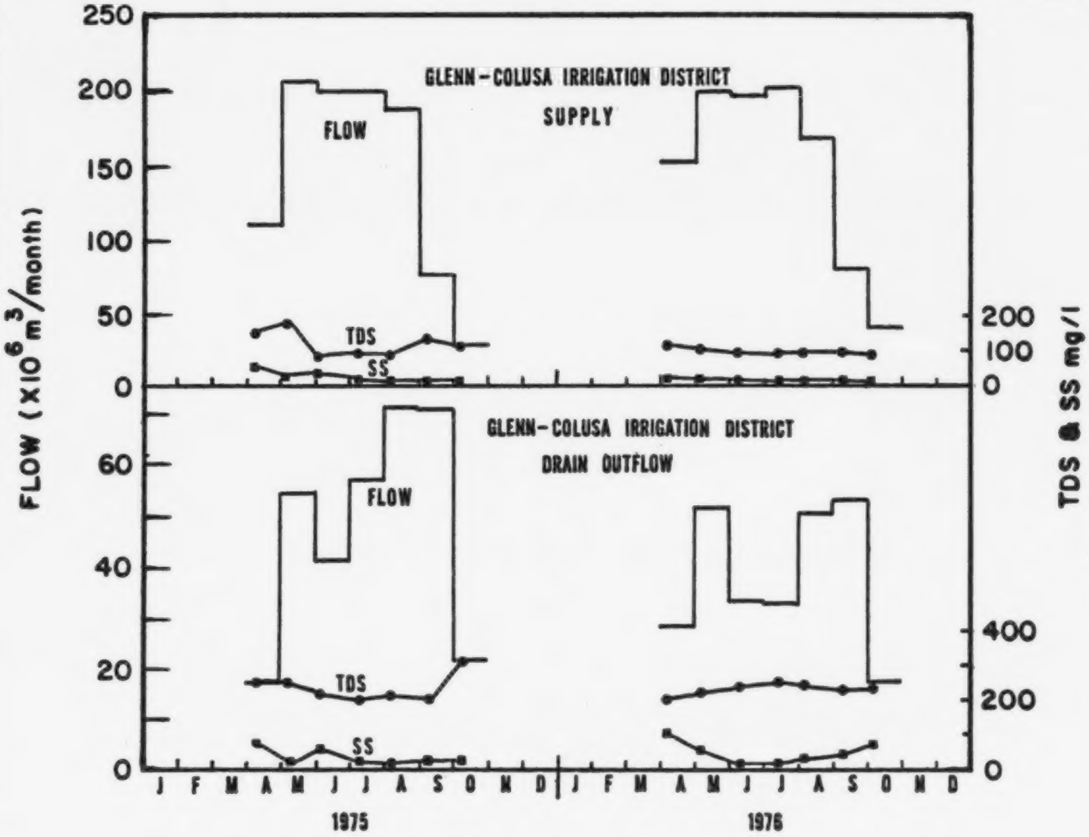

Figure 12. Monthly flows, TDS, and SS in Glenn-Colusa Irrigation District's supply water and drain outflow.

drained before harvesting. TDS and SS in the fresh supply water and drain waters are both low in concentration.

Table 7 presents the 1975 and 1976 irrigation season total water flows and flow-weighted average water quality for the district supply and drain waters as well as internal monitoring at 11 lateral drains. GCID diverted 1,030 x 10^6 m^3 (835,400 ac-ft) and 1,017 x 10^6 m^3 (824,400 ac-ft) of supply water for the 536 km^2 (132,440 ac) and 566 km^2 (140,230 ac) of irrigated lands in 1975 and 1976, respectively. The total surface discharge of return flows was about 300 x 10^3 m^3 (243,500 ac-ft) and 227 x 10^3 m^3 (183,800 ac-ft) for the 1975 and 1976 irrigation seasons, respectively. The EC and SS of drain outflow were, respectively, 2.5 and 2.4 times that of the supply water, typical values from irrigated croplands that are not salt-affected. In the lateral drains some variations are noted for the salinity and suspended matter parameters. The higher salinity levels reflect return flows from basin soils that are sodium-affected along with some salinity. Turbidity is generally low with some exceptions. Although much of the return flow is comprised of surface runoffs the concentrations of SS are not high since flooded rice fields act as settling basins for sediments. In contrast, Table 8 shows that

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TABLE 7. SEASONAL FLOWS AND WATER QUALITY IN GLENN-COLUSA IRRIGATION DISTRICT FOR THE 1975 AND 1976 IRRIGATION SEASONS

Station	Description	Year	Flow (10^6 m^3)	EC (mS/cm)	TDS (mg/ℓ)	Turbidity (JTU)	SS (mg/ℓ)
Supply water:							
D-14	GCID Main Canal	1975	1,030.5	0.180	116	15	24
		1976	1,016.9	0.133	97	8	12
Lateral drains:							
D-5	GCID 2047 @ Sidds Rd.	1975	30.8	0.315	187	16	31
		1976	14.6	0.322	197	21	48
D-2	GCID Bondurant	1975	6.5	0.335	201	19	37
		1976	2.6	0.271	177	8	29
D-3	GCID Drain 55	1975	61.9	0.307	177	8	16
		1976	39.4	0.301	185	9	13
D-6	Willow Creek	1975	26.9	0.320	189	19	33
		1976	19.4	0.341	210	13	18
D-1	Salmon Hole	1975	4.9	0.417	239	11	17
		1976	2.8	0.313	201	17	22
D-4	Logan Creek	1975	12.1	0.598	374	26	33
		1976	6.8	0.591	374	29	50
D-7	Hunter Creek	1975	21.3	0.361	212	40	42
		1976	12.8	0.339	200	21	35
D-8	Stone Corral Creek	1975	21.5	0.456	307	39	69
		1976	30.7	0.411	249	14	59
D-9	Kuhl Weir	1975	16.5	0.349	206	17	23
		1976	16.2	0.358	221	29	46
D-10	Section 25	1975	15.9	0.445	251	22	35
		1976	15.7	0.351	216	55	102
D-11	Freshwater Creek	1975	21.8	0.675	514	42	79
		1976	20.5	0.639	389	73	121
District Outflow:							
D-13	CBD at Davis Weir	1975	240.3	0.391	244	22	36
		1976	181.3	0.386	237	26	50

winter storm runoffs at the same sampling stations have smaller water flows, and higher salinity and suspended matter contents.

Table 9 contains detailed chemistry of GCID's supply and surface drainage waters representing the average of two and three samplings, respectively, for the 1975 and 1976 irrigation seasons. The supply water is a low-salt mixed bicarbonate type water while the return flow is a more saline sodium bicarbonate type water, but still considered relatively nonsaline. The nitrogen concentrations are low with organic N as the dominant solute species. The BOD values of 2.8 to 3.0 mg/l is largely due to suspended organic matter in the waters.

TABLE 8. STORM RUNOFFS[*] AND WATER QUALITY IN THE GLENN-COLUSA IRRIGATION DISTRICTS DURING THE NONIRRIGATION SEASONS (NOVEMBER THROUGH MARCH) OF 1975-76 AND 1976-77

Station†	Dates	Flow (10^6 m^3)	EC (mS/cm)	TDS (mg/ℓ)	Turbidity (JTU)	SS (mg/ℓ)
Lateral drain:						
D-5	1975-76	4.1	0.474	285	44	67
	1976-77	2.6	0.340	198	109	102
D-2	1975-76	3.1	0.291	183	14	20
	1976-77	2.1	0.335	196	528	407
D-3	1975-76	4.3	0.429	267	20	32
	1976-77	3.9	0.298	181	1,410	822
D-6	1975-76	7.5	0.353	205	46	66
	1976-77	2.5	0.332	200	91	60
D-1	1975-76	1.7	0.349	218	67	108
	1976-77	0.5	0.528	309	14	20
D-4	1975-76	6.8	0.840	529	25	38
	1976-77	6.0	0.882	543	39	53
D-7	1975-76	3.6	0.872	508	32	58
	1976-77	3.6	0.699	443	158	173
D-8	1975-76	7.2	0.607	354	32	70
	1976-77	8.9	0.770	405	1,550	1,940
D-9	1975-76	2.6	0.647	344	40	67
	1976-77	5.6	0.819	455	247	248
D-10	1975-76	3.5	0.567	329	23	13
	1976-77	2.8	0.612	346	236	190
D-11	1975-76	3.1	0.808	474	29	39
	1976-77	3.6	0.824	500	58	85
District outflow:						
D-13	1975-76	47.4	0.575	343	33	52
	1976-77	42.0	0.652	381	572	593

[*] Includes rim inflows from watershed.

[†] See station description, Table 7.

Table 10 summarizes inflow-outflow data for GCID during the 1975 and 1976 irrigation seasons. The average unit supply water was 1.86 m (6.1 ac-ft/ac) and average unit surface drainage, 0.48 m (1.58 ac-ft/ac) or 26% of supply water. The average unit TDS brought in with the irrigation water was 203 tons/km^2 and that discharged, 116 tons/km^2 or 57% of inflow. The average unit SS in the irrigation water was 34 tons/km^2 and that discharged, 20 tons/km^2 or 59% of flow. So, in GCID there were less salts and suspended matter discharged than brought in with the irrigation water. Even though the concentrations are higher in the discharge than in the supply waters

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TABLE 9. WATER CHEMISTRY OF SUPPLY AND DRAIN WATERS IN GLENN-COLUSA IRRIGATION DISTRICT IN THE IRRIGATION SEASONS

Parameters	1975		1976	
	Inflow (D-14)	Outflow (D-13)	Inflow (D-14)	Outflow (D-13)
EC, mS/cm	0.12	0.70	0.14	0.85
Solutes, mg/ℓ				
Na^+	5	83	7	104
Cu^{++}	10	33	6	34
Mg^{++}	5	25	6	30
K^+	1.2	5	1.0	3
HCO_3^-	60	258	71	278
Cl^-	2	41	4	58
SO_4^{--}	4	90	4	123
Nitrogen, mg N/ℓ				
Total N	0.92	1.15	1.04	1.30
Org. N	0.87	0.87	0.84	0.78
NH_4	0.03	0.24	0.06	0.25
NO_3	0.01	0.03	0.16	0.26
BOD, mg/ℓ	3.0	0.9	2.8	3.6
pH	-	8.0	-	8.3

TABLE 10. ANALYSIS OF INFLOW AND OUTFLOW OF WATER, TDS, AND SS IN GLENN-COLUSA IRRIGATION DISTRICT DURING THE 1975 AND 1976 IRRIGATION SEASONS

Parameter	Date	Supply	Drain
Total area, km^2	1975	536.2	536.2
	1976	565.6	565.6
Total water, 10^6 m^3	1975	1,030.5	300.4
	1976	1,016.9	226.7
Unit water, m^3/m^2	1975	1.92	0.56
	1976	1.80	0.40
Total TDS, tons	1975	119,563	73,304
	1976	103,641	53,744
Unit TDS, tons/km^2	1975	223	137
	1976	183	95
Total SS, tons	1975	24,737	10,816
	1976	12,821	11,338
Unit SS, tons/km^2	1975	44	19
	1976	23	20

(Table 7), the volumes are much less and, therefore, the mass emissions are smaller. Data will be presented later that indicate sediments tend to settle out in flooded rice. Since the soils are not accumulating salts, except in localized areas, salts are either being leached into the groundwater or being precipitated out in the crop root zone as insoluble minerals.

In addition to these district-wide investigations, five commercial rice fields in GCID were monitored in the 1975 as well as 1976 irrigation season. That data will be presented later under Special Studies.

BROADVIEW WATER DISTRICT

Broadview Water District (BWD) serves 40 km^2 (10,000 ac) of cropland and is a member of the Mendota-Crows Landing Return Flow Group (Figure 5). BWD has a unique irrigation system in that surface return flows have not been discharged since 1956. Figure 13 shows the layout of the irrigation and drainage system. For water distribution fresh canal water is lifted from the Delta-Mendota Canal at BWD-5. Surface return flows generated within this district along with surface inflows (BWD-1, -2) from contiguous irrigated tracts of land are collected in a large drain running in a northwesterly direction at the district boundary. The return flows consisting of surface runoffs and collected tile effluents and intercepted groundwater are pumped

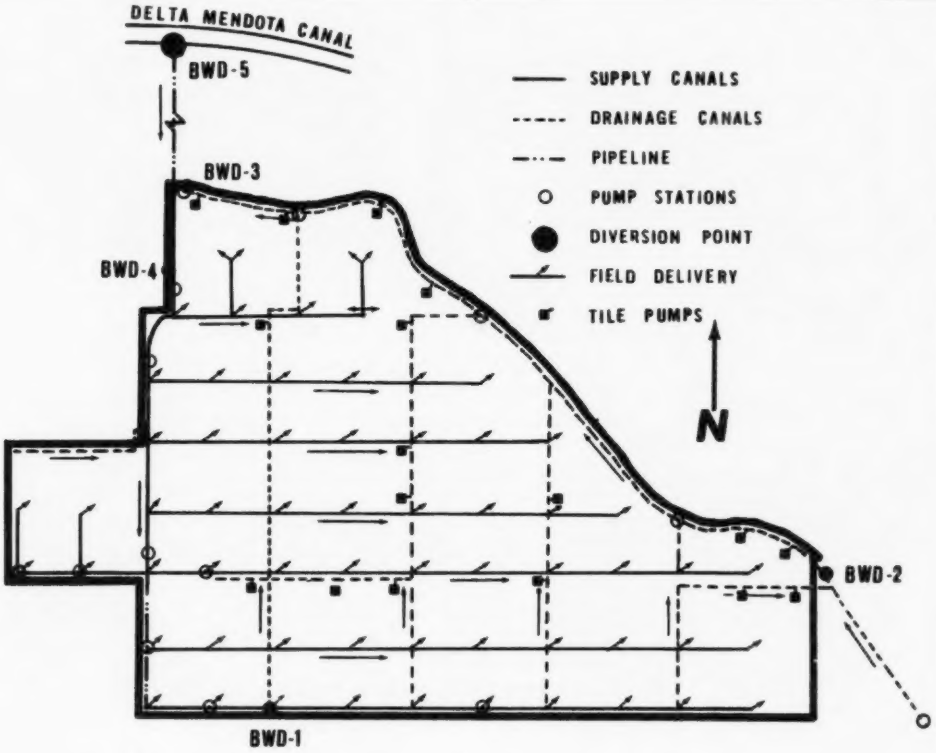

Figure 13. Network of supply and drainage systems in Broadview Water District.

into the district main canal near BWD-3. The blended fresh and drain waters are then delivered to growers. Station BWD-4 monitors the delivered water. The main canal runs in a southerly direction along the western district boundary and water is distributed to the fields through laterals running in an easterly direction. The district drainage canals that collect surface runoffs and tile effluents run in a northerly direction and are stored temporarily in a deep drain along the northeastern and northern boundaries before being recirculated into the distribution system near BWD-3. About half of this area is tile-drained because of rising water table.

Table 11 summaries salinity data for 14 soil profiles (sampling sites labelled as BWD-S in Figure 14) sampled to the water table, ranging from 1.5 to 4.9 m (5 to 16 ft) beneath the land surface. Given are the mean and standard deviations for electrical conductivity of soil saturation extracts; estimates of soluble salts calculated from EC_e and soil saturation percentage, the laboratory reference water content used to obtain the soil solution; gypsum ($CaSO_4 \cdot 2H_2O$), a naturally present soil mineral which contributes to soil salinity; and boron in the soil solution extract, a toxic element to most plants. The mean and standard deviations reported reflect considerable spatial variability. The highest salinities were located at BWD-S14, -S39, -S40, and EC_e in the surface 0.15 m was higher than the 0.15 to 0.3 m depth. The dominant soil is Panoche, with textures ranging from loam to clay.

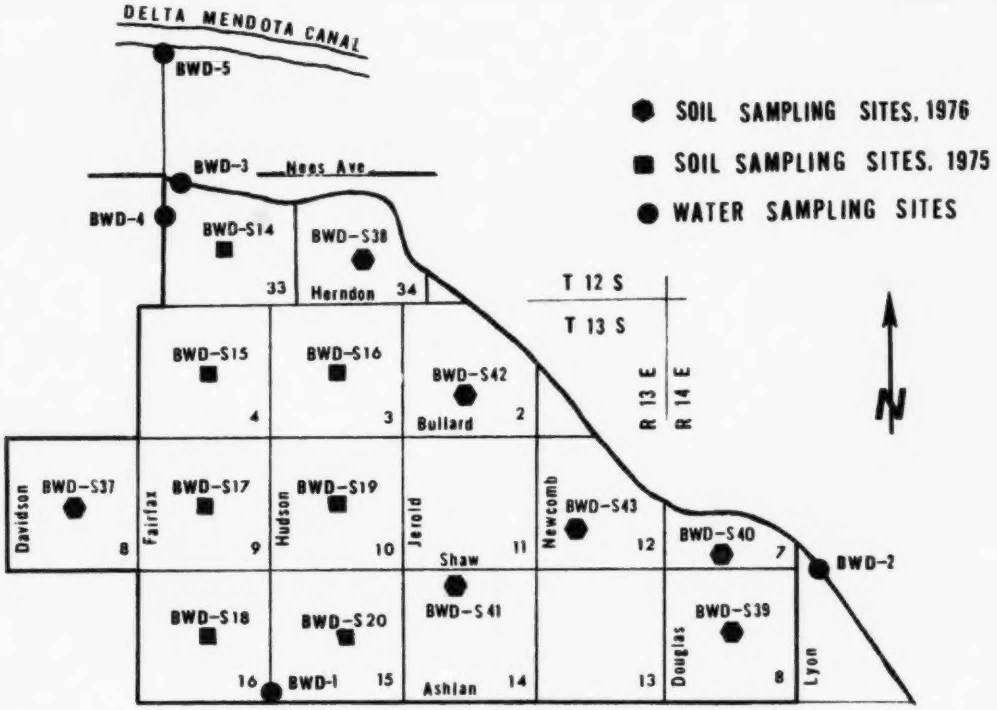
DELTA MENDOTA CANAL
BWD-5
● SOIL SAMPLING SITES, 1976
■ SOIL SAMPLING SITES, 1975
● WATER SAMPLING SITES
BWD-3
Nees Ave.
BWD-4
BWD-S14
BWD-S38
33
Herndon
34
T 12 S
T 13 S
BWD-S15
BWD-S16
BWD-S42
4
3
Bullard
2
R 13 E
R 14 E
N
Davidson
BWD-S37
8
Fairfax
BWD-S17
9
Hudson
BWD-S19
10
Jerold
Shaw
11
Newcomb
BWD-S43
12
BWD-S40
7
BWD-2
BWD-S18
BWD-S20
BWD-S41
BWD-S39
16
BWD-1
15
Ashlan
14
13
Douglas
8
Lyon

Figure 14. Soil and water sampling sites in Broadview Water District.

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TABLE 11. SUMMARY OF PROFILE SOIL SALINITY IN BROADVIEW WATER DISTRICT

Soil depth		No. of samples	EC_e[*] (mS/cm)		Estimated[†] soluble salts (kg/m^3)		Gypsum[†] (kg/m^3)		Boron[‡] (mg/ℓ)	
(m)	(ft)		$\bar{x}$	S_x	$\bar{x}$	S_x	$\bar{x}$	S_x	$\bar{x}$	S_x
0-0.15	0-½	14	6.06	3.66	3.46	2.61	2.15	2.71	1.96	0.75
0.15-0.30	½-1	14	4.92	3.15	2.99	2.00	3.58	8.55	1.69	0.92
0.30-0.46	1-1½	7	3.37	2.14	2.06	1.62	10.86	27.32	1.11	0.90
0.46-0.61	1½-2	7	3.11	1.74	2.07	1.52	0.54	0.29	1.00	0.71
0.30-0.61	1-2	7	6.70	3.66	4.12	1.88	3.37	5.07	2.92	1.11
0.61-0.91	2-3	14	5.80	3.84	3.64	2.47	11.34	24.59	2.17	1.55
0.91-1.22	3-4	14	6.14	4.05	4.09	3.11	14.84	18.77	2.38	1.80
1.22-1.52	4-5	14	6.06	3.86	3.96	3.42	13.99	16.05	2.41	2.02
1.52-1.83	5-6	13	6.23	2.80	4.19	3.35	14.72	16.35	2.78	2.43
1.83-2.13	6-7	13	6.70	3.50	4.33	2.85	13.29	15.19	3.37	2.77
2.13-2.44	7-8	12	5.93	4.06	3.93	3.48	19.19	27.35	3.70	4.40
2.44-2.74	8-9	9	5.63	3.95	3.66	3.67	14.94	23.95	3.66	4.87
2.74-3.05	9-10	5	5.55	2.63	3.04	1.49	10.43	16.44	2.45	1.56
3.05-3.35	10-11	5	5.42	3.25	2.84	1.56	9.95	15.67	2.58	1.61
3.35-3.66	11-12	3	5.21	3.60	2.99	2.25	13.32	13.01	2.69	1.68
3.66-3.96	12-13	3	5.97	4.07	3.52	2.57	12.16	11.02	2.96	1.81
3.96-4.27	13-14	2	10.13	1.94	4.92	0.18	12.23	0.99	3.79	0.87
4.27-4.57	14-15	1	12.95	-	4.71	-	6.22	-	3.95	-
4.57-4.88	15-16	1	13.86	-	4.24	-	5.34	-	4.15	-

[*] EC_e = EC of soil saturation extract, $\bar{x}$ = mean, S_x = standard deviation of the mean.

[†] kg/m^3 = 0.74 tons/ac-ft soil.

[‡] mg/ℓ in soil saturation extact.

Table 12 contains the crop and yield data for the 1975-76 and 1976-77 periods. Barley and wheat are winter crops while cotton and tomatoes are the dominant summer crops. Most of these crops are irrigated by the furrow method and some of the close-growing crops by the border strip method. The yields obtained are considered good in spite of the presence of soluble salts and boron.

Table 13 presents monthly data on water flows and EC for the March through October period in 1975 and 1976. It is noted that the blend of fresh canal water and captured drain water for BWD irrigation is about half and half. The average EC of the captured drain water was 3.1 mS/cm (3.1 mmhos/cm) and the resultant mixed water, 2.1 mS/cm. The EC of BWD's supply water is quite saline when compared to GCID's average EC of 0.16 mS/cm.

Table 14 contains additional water quality data. The rim inflows of surface waters into BWD are of two different qualities. BWD-1 monitors mainly tailwater runoffs and BWD-2, a mix of surface and subsurface drain waters. The quality of water captured at Station BWD-3 is moderately saline and contains about 2 mg/l boron while the diverted canal supply water is of good quality. The irrigation water delivered to the growers is moderately saline. The 1976 EC data on BWD-4 encompasses January through December and, therefore, are different than that shown in Table 13.

Table 15 contains more detailed chemical analyses for dissolved mineral salt and N species, based on four water samplings in March, June and September of 1976, and January 1977. The water diverted from the Delta-Mendota Canal is somewhat similar to that of GCID's drain water. The captured drain water is quite saline containing predominately sodium and sulfate ions along with some calcium and chloride ions. The sources of these ions are leaching of gypsum (Ca and SO_4), desorption of exchangeable sodium (Na), and concentration of applied water by ET (Cl). The drain water also contains high concentrations of nitrogen, mainly nitrates in contrast to the lower total nitrogen and dominance of organic nitrogen in GCID (Table 9). Table 15 clearly shows significant quality impacts from the blending of drain water into fresh water at BWD.

Although monthly surface water measurements are available, a complete water balance has not been made for BWD because of unknown quantities of subsurface flows, both vertically and laterally. Nevertheless, an appraisal was made on the annual transfers of TDS for the 1976 calendar year for a case of 50-50 blend of fresh canal water and captured drain waters. Table 16 shows that the rate of external inputs of TDS into BWD from the Delta-Mendota Canal was 130 tons/km^2/yr as compared to an average of 203 tons/km^2/yr for GCID (Table 10). But, unlike GCID, BWD does not discharge its surface return flows since the drain waters are captured and completely reused. Because of this particular recirculation practice, the internal circulation of saline drain waters contributes heavily to the 1,340 tons/km^2/yr of TDS actually delivered to the irrigated land. Another estimate on annual flow of TDS for captured drain water is obtained by difference, which is somewhat different than the measured data. Such differences in measured and calculated values occur because of errors associated with measuring water flows as well as in measuring EC that was obtained only once a month. The significance of this

TABLE 12. CROP AND YIELD DATA FOR BROADVIEW WATER DISTRICT FOR THE 1975-77 PERIOD

Crop	Year	Area harvested		Average yield	
		km^2	ac		
Cotton	1975-76	10.82	2,673	-	2.53 bales/ac
	1976-77	12.85	3,176	-	2.36 bales/ac
Barley	1975-76	10.31	2,547	0.55 kg/m^2	2.47 tons/ac
	1976-77	4.34	1,073	0.55 kg/m^2	2.46 tons/ac
Alfalfa seed	1975-76	4.43	1,094	80.0 kg/m^2	754 lbs/ac
	1976-77	3.59	887	60.0 kg/m^2	526 lbs/ac
Melons	1975-76	1.25	310	-	212 cartons/ac
	1976-77	1.21	300	-	220 cartons/ac
Tomatoes	1975-76	12.04	2,976	6.07 kg/m^2	27.1 tons/ac
	1976-77	7.96	1,967	5.04 kg/m^2	22.5 tons/ac
Sugar beets	1975-76	1.66	411	7.24 kg/m^2	32.3 tons/ac
	1976-77	2.11	521	7.33 kg/m^2	32.7 tons/ac
Wheat	1975-76	3.10	766	0.52 kg/m^2	2.31 tons/ac
	1976-77	4.25	1,050	0.45 kg/m^2	2.00 tons/ac
Total	1975-76	37.48	9,262	-	-
	1976-77	36.32	8,974	-	-

TABLE 13. MONTHLY FLOWS AND EC OF FRESH CANAL WATER (BWD-5) CAPTURED DRAIN WATER (BWD-3), AND RESULTANT SUPPLY WATER (BWD-4) FOR BROADVIEW WATER DISTRICT

Month	Year	BWD-5		BWD-3		BWD-4	
		Flow (10^6 m^3)	EC (mS/cm)	Flow (10^6 m^3)	EC (mS/cm)	Flow (10^6 m^3)	EC (mS/cm)
Mar	1975	4.0	-	2.5	-	6.5	-
	1976	1.7	0.50	2.0	4.81	3.8	3.23
Apr	1975	1.5	-	2.0	-	3.5	-
	1976	1.0	0.39	1.6	3.52	2.6	3.64
May	1975	1.6	0.56	1.9	4.44	3.5	3.40
	1976	2.2	0.31	2.3	4.18	4.5	4.10
Jun	1975	3.6	0.45	3.8	2.12	7.4	1.04
	1976	3.3	0.48	2.7	2.47	6.0	1.61
Jul	1975	3.3	0.73	3.1	2.04	6.4	1.55
	1976	3.2	0.50	2.4	2.19	5.7	1.31
Aug	1975	1.4	0.60	1.7	1.92	3.1	1.07
	1976	0.9	0.48	1.3	1.58	2.2	1.06
Sep	1975	0.4	0.26	0.5	1.85	0.9	0.71
	1976	0.03	0.42	0.04	3.90	0.07	3.79
Oct	1975	1.3	0.41	0.8	3.26	2.1	1.41
	1976	0.4	0.79	0.05	6.06	0.4	-
Total or	1975	17.1	0.50	16.3	2.61	33.4	1.53
Average	1976	12.7	0.48	12.4	3.59	25.3	2.68

TABLE 14. FLOW-WEIGHTED AVERAGE WATER QUALITY FOR BROADVIEW WATER DISTRICT

Station	Description	Year	EC (mS/cm)	TDS (mg/ℓ)	Turbidity (JTU)	SS (mg/ℓ)	B (mg/ℓ)
BWD-1	Rim inflow	1975	0.64	358	116	292	0.3
		1976	0.60	322	1,150	930	0.3
BWD-2	Rim inflow	1975	1.32	835	102	279	0.7
		1976	1.47	883	71	106	0.8
BWD-3	Captured drain water	1975	2.51	1,650	153	449	1.8
		1976	2.99	2,080	175	283	2.2
BWD-5	Diverted canal water	1975	0.55	314	38	129	0.2
		1976	0.41	272	23	55	0.2
BWD-4	Mixed supply water	1975	1.55	1,030	78	237	0.9
		1976	2.18	1,480	110	217	1.6

TABLE 15. WATER CHEMISTRY OF DIVERTED FRESH WATER (BWD-5), CAPTURED DRAIN WATER (BWD-3), AND BLENDED IRRIGATION WATER (BWD-4) FOR BROADVIEW WATER DISTRICT IN 1976-77

Parameters	BWD-5	BWD-3	BWD-4
EC, mS/cm	0.47	3.56	2.88
pH	8.2	8.1	8.2
Solutes, mg/ℓ			
Na^+	51	494	376
Ca^{++}	22	212	161
Mg^{++}	13	82	60
HCO_3^-	95	177	157
Cl^-	72	513	406
SO_4^{--}	48	1,004	713
Nitrogen, mg N/ℓ			
Total N	1.60	17.58	11.67
Org. N	0.80	1.62	1.00
NH_4	0.03	0.35	0.07
NO_3	0.76	15.43	10.50
BOD	0.8	1.6	1.0

appraisal is that in recirculating drain water, salts are also being recirculated. If it were not for deep percolation and/or unintercepted lateral subsurface flows, there would be a gradual incremental rise in TDS in both the soils and drain water, because of chemical weathering of soil minerals, mainly gypsum, and concentration of salts in the soil solution by ET.

TABLE 16. ANNUAL TDS TRANSFERS IN BROADVIEW WATER DISTRICT FOR 1976

Parameter	Delivered irrigation water (BWD-4)	Diverted canal water (BWD-5)	Captured drain water (BWD-3)	Calculated difference*
TDS, tons	51,540	4,990	34,140	46,550
TDS, tons/km^{2}†	1,340	130	890	1,210

*(BWD-4) - (BWD-5)

† based on 38.2 km^{2} of cropland.

PANOCHE DRAINAGE DISTRICT

The 178 km^{2} (44,000 ac) Panoche Drainage District (PDD) is another entity studied in the Mendota-Crows Landing Return Flow Group (Figure 5). PDD is comprised of Panoche Water District and three small water districts, Figure 15.

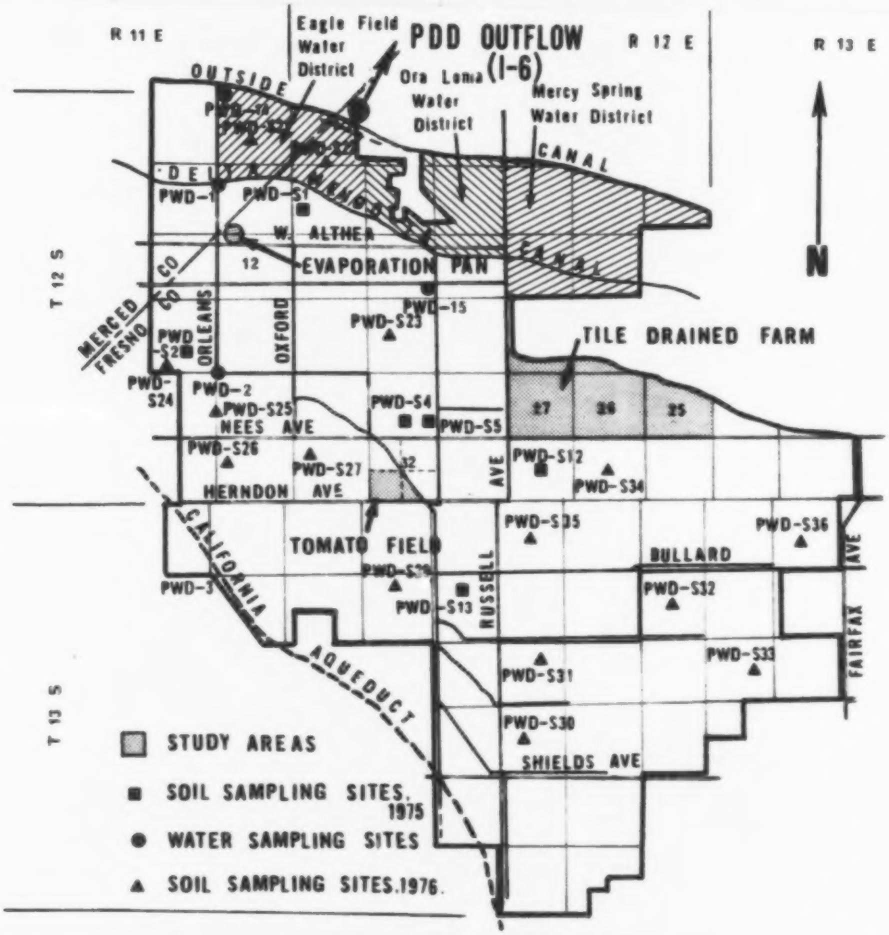
R 11 E
Eagle Field Water District
PDD OUTFLOW (I-6)
R 12 E
R 13 E
OUTSIDE
Oro Loma Water District
Mercy Spring Water District
CANAL
DELTA MENDOTA CANAL
PWD-1
PWD-S1
W. ALTHEA
12
EVAPORATION PAN
PWD-15
PWD-S23
N
T 12 S
CO
CO
MERCED
FRESNO
ORLEANS
OXFORD
PWD-S2
TILE DRAINED FARM
PWD-S24
PWD-2
PWD-S25
NEES AVE
PWD-S4
PWD-S5
27
26
25
PWD-S26
PWD-S27
32
AVE
PWD-S12
PWD-S34
HERNDON AVE
CALIFORNIA
TOMATO FIELD
PWD-S35
PWD-S36
BULLARD
AVE
PWD-S29
PWD-S13
RUSSELL
PWD-3
PWD-S32
FAIRFAX
AQUEDUCT
PWD-S33
PWD-S31
T 13 S
PWD-S30
SHIELDS AVE
STUDY AREAS
SOIL SAMPLING SITES, 1975
WATER SAMPLING SITES
SOIL SAMPLING SITES.1976.

Figure 15. Soil and water sampling sites in Panoche Drainage District.

In addition to district-wide assessments like those conducted for BWD and GCID, two on-farm studies were conducted in PDD. The on-farm studies in the tomato field and tile-drained farm will be reported later under Special Studies.

Figure 16 shows a layout of the irrigation and drainage system in the PDD. This district obtains water imported through the Delta-Mendota Canal as well as the California Aqueduct. Water diverted from the former is lifted by a series of pumps up to as much as 45.7 m (150 ft) in a southerly direction and then distributed in an easterly direction. On the other hand, water diverted from the California Aqueduct flows by gravity in a northerly as well as an easterly direction. The distribution system in Panoche Water District consists of 82 km (51 miles) of canals, 29 km (18 miles) of which is smaller, concrete-lined laterals. The elevation in the district varies from 50 to 98 km (165 to 320 ft) above sea level. The drainage network conforms to the slope in the ground surface in an easterly and northerly direction. Return

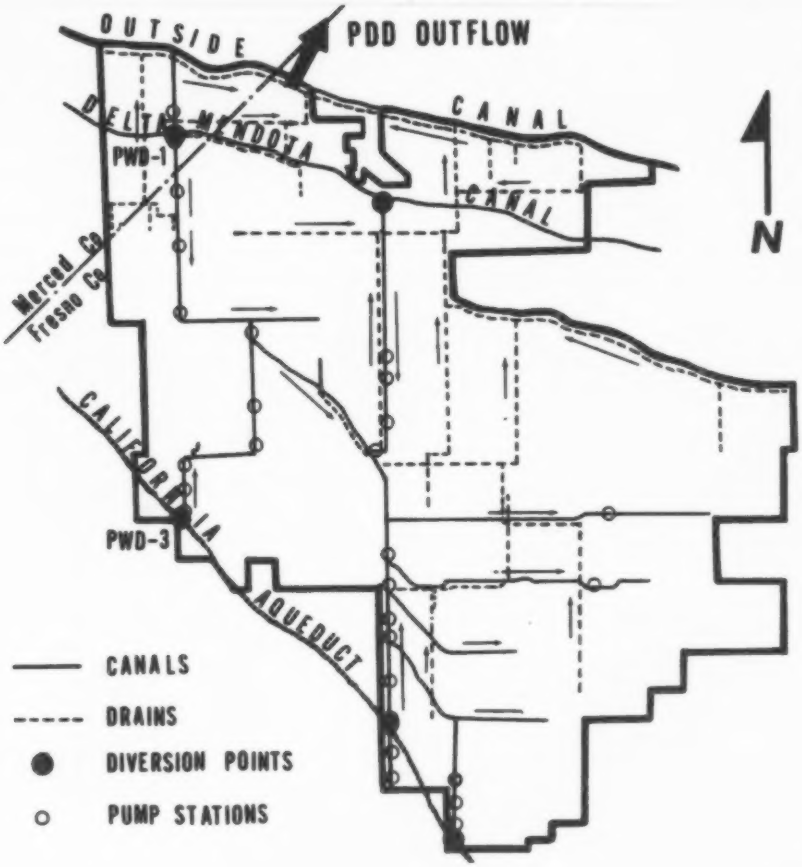
OUTSIDE CANAL
PDD OUTFLOW
DELTA-MENDOTA CANAL
N
PWD-1
Merced Co
Fresno Co
CALIFORNIA AQUEDUCT
PWD-3
CANALS
DRAINS
DIVERSION POINTS
PUMP STATIONS

Figure 16. Network of supply and drainage canals in Panoche Drainage District.

flows in PDD are collected by the Panoche Drain that discharges into the southern portion of the Grasslands Water District where much reuse takes place.

Table 17 gives the mean and standard deviation of salinity parameters measured at 29 sampling sites (labelled PWD-S in Figure 15). As in BWD, the soil profiles were sampled to the existing depth of water table. About one-third of the sites had water tables at about 5 m (16 ft) or deeper, about one-third between 3 and 5 m (9 and 16 ft), and another third at about 2 m (7 ft) or shallower. The more salt-affected profiles were located at the lower elevations north of a diagonal line connecting PWD-S35 and PWD-S4 (center of Figure 15), which coincidentally is also the dividing line for the tile-drained, shallow water-table fields. The soil samples represent a bimodel population of relatively non-saline, low-boron and nongypsiferous soils and saline, high-boron, gypsiferous soils. The large standard deviation from the mean is indicative of the wide range of values found in the Panoche soil series.

Table 18 contains the crop and yield data for Panoche Water District, the major entity in the PDD. The main summer crops are cotton, tomatoes and cantaloupes while the main winter crops are barley and wheat. The row crops are furrow irrigated while the small grains are irrigated by the border method. About 15% of the irrigated lands are initially sprinkler irrigated for seed germination in the furrow beds. The yields obtained for these crops are considered good and neither salinity nor boron appears to have a significant effect. In regard to the latter, crops sensitive to boron are seldom planted in boron-affected lands.

Figure 17 depicts the monthly water flows, TDS, and SS for both the supply and drain outflow. Like in GCID, the peak flow of supply water occurs in midsummer. But, because of a longer growing season and double cropping, water is delivered nearly year round. Fall planted crops are frequently seeded in soils that have been pre-irrigated, and they continue to receive irrigation when winter rainfall is inadequate. The sharp drop in water delivery in April 1976 is attributed to a heavy rainfall. The rise in TDS in September and October 1976 is due to low delta outflows from the Sacramento-San Joaquin Delta which contribute to seawater intrusion. The drain outflow from PDD appears to follow more or less the trend in the supply water. The concentrations of TDS, however, are much higher due to the leaching of salt-affected lands.

Table 19 presents data on supply and drain outflow for PDD in the monitored periods in 1975 and 1976. The imported supply water was obtained from the Delta-Mendota Canal and the California Aqueduct in about a 2:1 ratio. Unlike GCID and BWD, capture and reuse of drain water is done mainly at the on-farm level. PDD and the neighboring Central California Irrigation District captured only 10.3 and 15.1 x 10^6 m^3 of water in 1975 and 1976, respectively. Most of the drain water was collected in Panoche Drain and discharged into the Grasslands Water District. The unit applied water, based on 161.6 km^2 and 167.2 km^2 of irrigated lands, respectively, in 1975 and 1976, was about 1.0 m (3.3 ft) in contrast to 1.9 m (6.2 ft) for GCID. The unit drainage

TABLE 17. SUMMARY OF PROFILE SOIL SALINITY IN PANOCHE DRAINAGE DISTRICT

Soil depth		No. of samples	EC$_e$* (mS/cm)		Estimated† soluble salts (kg/m^3)		Gypsum† (kg/m^3)		Boron‡ (mg/ℓ)	
(m)	(ft)		$\bar{x}$	S_x	$\bar{x}$	S_x	$\bar{x}$	S_x	$\bar{x}$	S_x
0-0.15	0-½	29	2.59	2.11	1.44	1.22	0.67	1.05	1.48	1.45
0.15-0.30	½-1	29	2.68	2.74	1.49	1.40	0.77	1.27	1.54	1.37
0.30-0.46	1-1½	13	2.74	2.17	1.91	1.84	0.52	0.56	1.97	0.87
0.46-0.61	1½-2	13	3.18	2.49	2.27	2.35	0.71	1.07	2.26	1.28
0.30-0.61	1-2	16	2.42	3.15	1.34	1.42	0.79	0.61	2.12	3.26
0.61-0.91	2-3	29	3.42	4.22	2.21	2.57	3.23	7.65	2.72	3.36
0.91-1.22	3-4	29	3.84	3.88	2.35	2.63	5.48	12.19	3.05	3.39
1.22-1.52	4-5	29	4.19	4.00	2.54	2.61	6.60	12.77	2.85	2.75
1.52-1.83	5-6	29	4.27	3.78	2.83	3.40	6.16	9.70	3.08	3.07
1.83-2.13	6-7	28	4.05	3.61	2.71	3.52	6.44	10.88	3.22	3.43
2.13-2.44	7-8	23	4.28	4.21	2.77	3.26	9.06	11.97	3.57	4.66
2.44-2.74	8-9	20	3.56	3.20	2.10	2.07	8.94	11.73	3.08	4.04
2.74-3.05	9-10	18	3.32	2.98	2.02	2.11	8.35	11.52	2.89	4.23
3.05-3.35	10-11	16	3.59	3.30	1.96	2.23	12.37	19.20	3.18	5.10
3.35-3.66	11-12	13	2.71	2.98	1.45	1.94	9.36	16.33	1.83	1.78
3.66-3.96	12-13	11	2.96	3.40	1.56	2.14	9.83	15.11	1.62	1.64
3.96-4.27	13-14	11	2.86	3.32	1.52	2.10	9.31	13.27	1.69	1.63
4.27-4.57	14-15	11	2.85	3.43	1.59	2.25	8.24	11.44	1.66	1.64
4.57-4.88	15-16	10	2.64	3.24	1.30	2.01	5.11	9.32	1.59	1.55
4.88-5.18	16-17	8	3.00	3.60	1.57	2.30	6.42	15.67	1.90	2.18
5.18-5.49	17-18	7	1.91	1.82	0.90	1.04	7.32	16.54	1.11	0.60
5.49-5.79	18-19	6	2.11	1.92	0.91	0.96	3.51	5.79	1.11	0.52
5.79-6.10	19-20	5	1.69	1.52	0.70	0.80	1.94	4.03	1.37	0.96
6.10-6.40	20-21	5	1.92	1.70	0.76	0.68	2.07	4.29	1.41	0.97
6.40-6.71	21-22	4	1.95	2.32	0.85	1.05	1.20	1.96	1.17	0.61
6.71-7.01	22-23	3	2.38	2.91	1.10	1.39	1.36	2.00	1.29	0.80
7.01-7.32	23-24	3	2.68	3.31	1.16	1.45	2.40	3.79	1.47	1.01
7.32-7.62	24-25	2	3.25	3.62	1.06	1.21	0.18	0.04	1.93	0.75
7.62-7.92	25-26	1	.73	-	0.26	-	0.16	-	1.50	-
7.92-8.23	26-27	1	.74	-	0.21	-	0.16	-	2.00	-

[*] EC$_e$ = EC of soil saturation extracts, $\bar{x}$ = mean, S_x = standard deviation of the mean.

[†] kg/m^3 = 0.74 tons/ac-ft soil.

[‡] mg/ℓ in soil saturation extract.

TABLE 18. CROP AND YIELD DATA FOR PANOCHE WATER DISTRICT FOR THE 1975-77 PERIOD

Crop	Year	Area harvested km^2	Area harvested ac	Average yield	Average yield
Almonds	1975-76	0.48	118	0.07 kg/m^2	641 lbs/ac
	1976-77	0.36	90	0.11 kg/m^2	1,000 lbs/ac
Alfalfa Hay	1975-76	1.91	472	1.18 kg/m^2	10,485 lbs/ac
	1976-77	2.93	724	0.98 kg/m^2	8,788 lbs/ac
Alfalfa Seed	1975-76	3.59	886	0.06 kg/m^2	510 lbs/ac
	1976-77	1.57	388	0.01 kg/m^2	129 lbs/ac
Barley	1975-76	6.00	1,483	0.55 kg/m^2	4,900 lbs/ac
	1976-77	11.62	2,871	0.52 kg/m^2	4,640 lbs/ac
Beans	1975-76	-	-	-	-
	1976-77	2.83	700	0.15 kg/m^2	1,333 lbs/ac
Cantaloupes	1975-76	15.09	3,728	-	312 crates/ac
	1976-77	3.67	1,908	-	250 cartons/ac
Carrot Seed	1975-76	-	-	-	-
	1976-77	0.83	206	0.04 kg/m^2	337 lbs/ac
Corn	1975-76	3.04	750	4.57 kg/m^2	20.4 tons/ac
	1976-77	2.74	674	3.36 kg/m^2	15 tons/ac
Cotton	1975-76	44.53	11,004	-	1.96 bales/ac
	1976-77	58.59	14,477	-	2.07 bales/ac
Crenshaws	1975-76	0.97	240	-	800 crates/ac
	1976-77	0.97	240	-	700 cartons/ac
Garlic	1975-76	1.39	344	1.39 kg/m^2	6.2 tons/ac
	1976-77	0.32	80	2.07 kg/m^2	9.25 tons/ac
Garlic	1975-76	-	-	-	-
	1976-77	0.15	38	-	74 cartons/ac
Honeydews	1975-76	0.55	133	-	625 crates/ac
	1976-77	0.85	210	-	600 cartons/ac
Lettuce	1975-76	3.49	862	-	674 cartons/ac
	1976-77	2.20	544	-	613 cartons/ac
Oats	1975-76	1.82	450	2.15 kg/m^2	9.6 tons/ac
	1976-77	2.74	676	2.02 kg/m^2	9 tons/ac
Pasture	1975-76	5.00	1,236	-	-
	1976-77	0.64	157	-	-
Peppers	1975-76	-	-	-	-
	1976-77	0.41	101	0.27 kg/m^2	1.2 tons/ac

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TABLE 18. (continued)

Crop	Year	Area harvested		Average yield	
		km^2	ac		
Prunes	1975-76	0.51	127	1.00 kg/m^2	4.44 tons/ac
	1976-77	-	-	-	-
Rice	1975-76	-	-	-	-
	1976-77	0.57	140	0.38 kg/m^2	3,400 lbs/ac
Safflower	1975-76	6.54	1,617	-	25 cwt/ac
	1976-77	1.89	467	0.30 kg/m^2	1.35 tons/ac
Sugar Beets	1975-76	4.33	1,069	6.28 kg/m^2	28 tons/ac
	1976-77	2.98	737	6.63 kg/m^2	29.56 tons/ac
Tomatoes	1975-76	30.38	7,506	6.50 kg/m^2	29 tons/ac
	1976-77	17.41	4,302	5.38 kg/m^2	23.98 tons/ac
Vegetable Seeds	1975-76	0.49	120	0.73 gm/m^2	6.5 lbs/ac
	1976-77	-	-	-	-
Wheat	1975-76	11.83	2,923	0.61 kg/m^2	2.7 tons/ac
	1976-77	3.83	947	0.54 kg/m^2	2.4 tons/ac
Total	1975-76	141.92	35,070	-	-
	1976-77	125.37	30,979	-	-

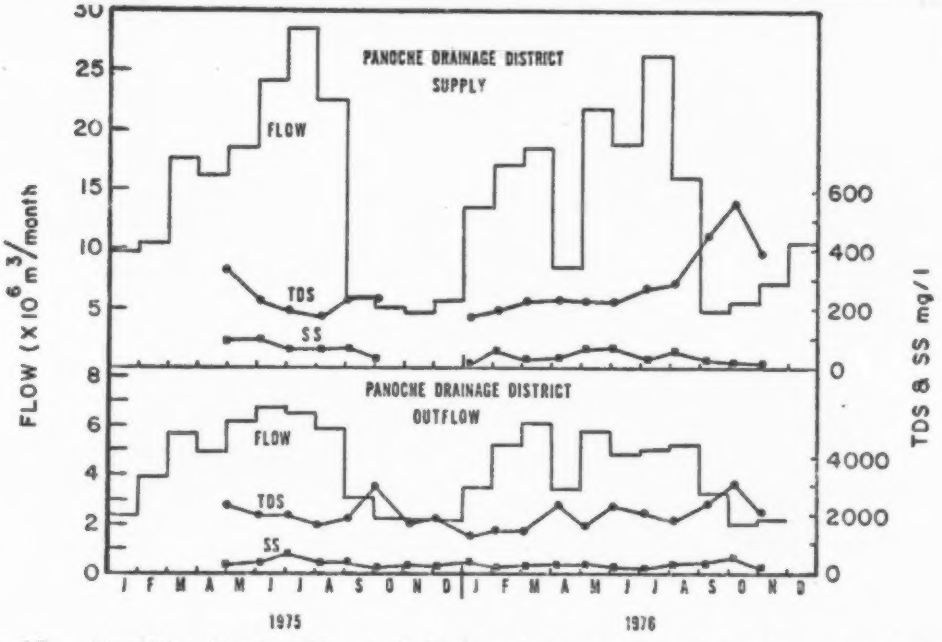

Figure 17. Monthly flow, TDS, and SS in the supply and drainage waters of Panoche Drainage District.

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TABLE 19. SUPPLY AND DISCHARGE WATERS FOR PANOCHE DRAINAGE DISTRICT

Description	Jan-Oct 1975	Jan-Dec 1976
Supply:		
Delta-Mendota Canal, 10^6 m^3	107.2	106.7
California Aqueduct, 10^6 m^3	51.6	60.4
Total, 10^6 m^3	158.8	167.1
Unit supply, m^3/m^2	0.98	1.09
Recapture:		
Panoche Water District, 10^6 m^3	1.8	5.3
Central California Irrigation District, 10^6 m^3	8.5	9.8
Total, 10^6 m^3	10.3	15.1
Total, % of supply	6.5	9.0
Discharge:		
Panoche Drain, 10^6 m^3	40.4	41.2
Panoche Drain, % of supply	25.4	24.7
Unit discharge, m^3/m^2	0.28	0.29

was about 0.3 m (1.0 ft), which is slightly less than for GCID (Table 10), and equivalent to about 25% of the supply water.

Table 20 presents water quality of supply and drainage waters in PDD. The two sources of supply water are comparable in quality since they are pumped from the same location in the Southern Delta, but the Delta-Mendota Canal water contains appreciably more suspended matter than the California Aqueduct because the latter is completely concrete-lined and the former is not. The return flow consisting of a mix of surface runoffs and collected subsurface drainage is comparatively high in salinity, suspended matter, and boron. Table 21 gives more details on water quality for the 1976-77 season, which was similar to the 1975-76 season. Both supply waters contain low

TABLE 20. SEASONAL WATER QUALITY OF SUPPLY AND DRAIN WATERS IN PANOCHE DRAINAGE DISTRICT

Station	Description	Year	EC (mS/cm)	TDS (mg/1)	Turbidity	SS (mg/1)	B (mg/1)	pH
Supply								
PWD-1	Delta-Mendota Canal	1975	0.35	211	38	102	0.2	-
		1976	0.45	268	30	56	0.1	8.0
PWD-3	California Aqueduct	1975	0.42	236	12	19	0.2	-
		1976	0.45	266	13	14	0.1	8.2
Discharge:								
I-6	Panoche Drain	1975	3.07	2,050	126	348	4.8	-
		1976	2.76	1,880	170	306	4.0	8.0

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TABLE 21. WATER CHEMISTRY OF SUPPLY AND DRAINAGE WATERS IN PANOCHE DRAINAGE DISTRICT FOR THE 1976-1977 SEASON

Parameters	Delta-Mendota Canal (PWD-1)	California Aqueduct (PWD-3)	Panoche Drain (I-6)
Solutes, mg/ℓ			
Na^+	53	56	398
Ca^{++}	26	26	179
Mg^{++}	14	12	58
HCO_3^-	114	101	186
Cl^-	84	82	430
SO_4^{--}	51	44	746
Nitrogen, mg N/ℓ			
Total N	1.63	2.30	16.63
Org. N	0.83	0.84	1.38
NH_4	0.04	0.05	0.15
NO_3	0.74	1.41	15.01
BOD, mg/ℓ	1.0	1.1	1.1

levels of dissolved minerals and nitrogen, and the drain water is much more concentrated. Like the captured drainage water in BWD, water in the Panoche Drain contains appreciable amounts of sodium, sulfate, chloride, and nitrate. The unit TDS discharged as measured at I-6 was about 490 tons/km^2 in 1976 as compared to about 116 tons/km^2 in GCID, mainly due to leaching of the salt-affected soils in PDD.

LOS BANOS WILDLIFE AREA

Within the Mendota-Crows Landing Return Flow Group a mutually beneficial water arrangement has evolved among the various water users. During the irrigation season, part of the return flow generated by crop irrigators is utilized for the irrigation of native pastures that are grazed by cows and to maintain suitable upland and wetland habitats in private, state and federally-operated wildlife lands. One the other hand, during the nonirrigation season, the irrigation distribution system is used for delivery of freshwater to raise water levels in duck ponds to optimum levels for the wintering waterfowl on the Pacific Flyway.

The Los Banos Wildlife Area (Figures 5 and 18), operated by the California Department of Fish and Game, covers a 13-km^2 (3,200 ac) site. Table 22 lists the recreational usage for this wildlife area between July, 1974 and June, 1975. The single most important operational activity in this refuge, in terms of management, is the manipulation of water. Proper water management in this semiarid climate is necessary to establish and maintain both wetland and upland habitats. This wildlife area has about 24 km (80,000 lineal ft) of supply and drain ditches and about 1.6 km^2 (400 ac) of permanently impounded water. The 9.7 km^2 (2,400 ac) of marshland are annually ponded for water fowl starting in June and kept flooded until late April. In addition, irrigation of native and planted vegetation in upland areas are needed to provide food and cover for mammals and birds. As shown in Table 22, this area is utilized for a variety of purposes.

Figure 18 shows 13 sampling stations in and around the Los Banos Wildlife Area. As indicated in Table 23 and Figure 18, there are eight water inflow points to the refuge with a wide range in quality depending on the source of the water. LBWA-10 was chosen as the outflow monitoring station and the remaining four stations represent internal monitoring stations. LBWA-14 and -9 are discharge stations into Mud Slough downstream from LBWA-10, and LBWA-12 and -13 are inflow and outflow stations for Ruth Lake, which is a stocked warm water fishery. Major attempts were made to estimate water flows but with only partial success. The lack of suitable structures in the channel and flow characteristics made it impossible to estimate flows without incurring costs beyond the budget of this project. Based upon visual and measured observations, the main inflows of water into the refuge were Mud Slough (LBWA-4) and Boundary Drain (LBWA-5).

The San Luis Canal (LBWA-2 and LBWA-11) is moderately saline and contains relatively high concentrations of boron and nitrate that are indicative of return flows from tile-drained, salt-affected lands. On the other hand, the treated municipal sewage effluent (LBWA-3) discharged by the city of Los Banos has salinity and boron contents similar to San Luis Canal (LBWA-2), but the BOD is greater and the nitrogen is dominated by organic N and ammonium. Mud Slough inlet is of similar salinity and boron contents as San Luis Canal, but the BOD is greater since it drains grazed pastures irrigated with return flows. Although the total nitrogen is less, organic N is greater and nitrate is less than in San Luis Canal. The waters in Boundary Drain (LBWA-5) and West Delta Canal (LBWA-8) contain comparatively low boron concentrations, indicative of absence of collected subsurface drainage. The EC in LBWA-5 and LBWA-8 are much lower than the waters in LBWA-2, -3, or -4, and they appear to be mainly composed of surface runoffs from irrigated lands. In contrast, San Pedro Canal (LBWA-6) has water quality characteristics similar to the fresh water in the Delta-Mendota Canal. Hence the supply waters for this wildlife refuge vary widely as to source and in quality.

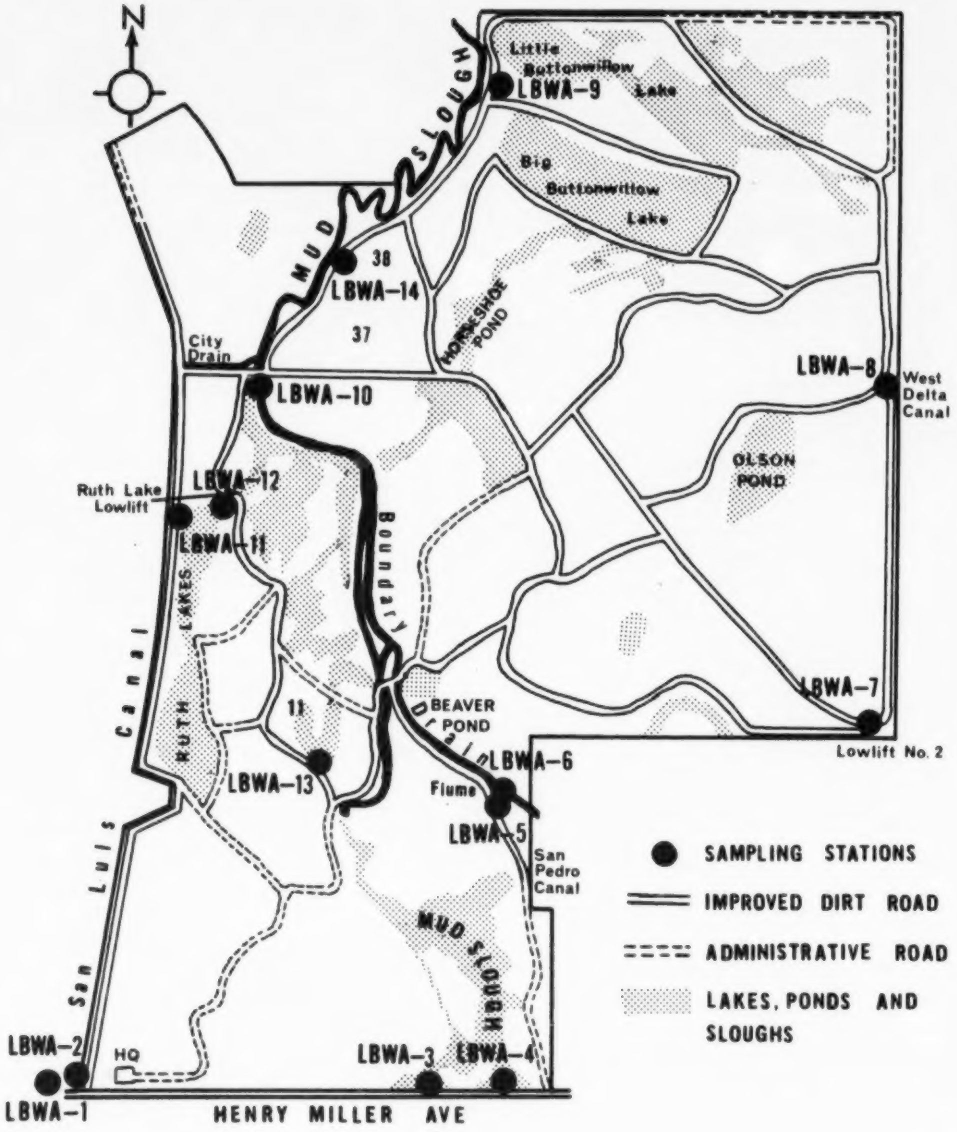
N
MUD SLOUGH
Little Buttonwillow Lake
LBWA-9
Big Buttonwillow Lake
38
LBWA-14
37
HORSESHOE POND
City Drain
LBWA-10
LBWA-8
West Delta Canal
OLSON POND
Ruth Lake Lowlift
LBWA-12
LBWA-11
RUTH LAKES
Boundary
San Luis Canal
11
BEAVER POND
Drain
LBWA-13
LBWA-6
LBWA-7
Lowlift No. 2
Flume
LBWA-5
San Pedro Canal
SAMPLING STATIONS
IMPROVED DIRT ROAD
ADMINISTRATIVE ROAD
LAKES, PONDS AND SLOUGHS
MUD SLOUGH
LBWA-2
HQ
LBWA-3
LBWA-4
LBWA-1
HENRY MILLER AVE

Figure 18. Map of the Low Banos Wildlife Area near the city of Los Banos.

LBWA-10 is the Mud Slough outlet station. Its quality is affected not only by Mud Slough inlet (LBWA-4) but also by the comingled return flows from most of the water supply sources cited. LBWA-14 is a discharge station for Fields 37 and 38 (Figure 18) that are devoted mainly to cropping with grain to serve as food and cover for pheasants, ducks, and other animals. The water quality varied significantly between 1975 and 1976 for LBWA-14 and probable reasons for this is not readily apparent. LBWA-9 is a station at the outflow point for Button Willow Lake, fed primarily by LBWA-8. Water for Ruth Lake

TABLE 22. RECREATIONAL USAGE OF THE LOS BANOS WILDLIFE AREA BETWEEN JULY 1974 AND JUNE 1975

	Season	Number of hunters	Harvest or number bagged
Hunting:			
Ducks, geese, coots	Oct. 19-Jan. 19	4,904	9,952
Pheasant	Nov. 16-Dec. 8	1,227	175
Rabbit	Jan. 20-Oct. 18	315	388
Total		6,446	
Nonhunting:	Number of people		
Fishing	8,419		
Frogging	373		
Sightseeing	1,161		
Nature Study	920*		
Camping	177†		
Activity Unknown	2,714		
Total	13,764		

* Includes organized groups from schools, ranging from elementary to university levels, birdwatching by various local Audobon Societies, etc.

† 571 registered visitors actually camped. Visitor registration form was not designed to indicate more than one activity and so the remainder presumably were recorded under other activities.

TABLE 23. WATER FLOWS AND WATER QUALITY IN THE LOS BANOS WILDLIFE AREA DURING THE IRRIGATION SEASONS OF 1975 AND 1976

Station	Description	Year*	Flow ($10^6 m^3$)	EC (mS/cm)	SS (mg/ℓ)	B (mg/ℓ)	Total N	Org.N (mg N/ℓ)	NH_4	NO_3	BOD (mg/ℓ)
Inflow:†											
LBWA-2	San Luis Canal	1975	3.0	2.26	171	3.6	4.9	1.0	0.6	3.0	2.1
		1976	1.4	2.60	126	3.6	8.3	1.1	0.2	7.0	2.6
LBWA-3	Municipal sewage effluent	1975	-	2.45	11	2.4	7.3	4.2	3.2	0.1	4.6
		1976	0.01	3.29	15	2.8	7.7	4.6	3.0	0.1	5.5
LBWA-4	Mud Slough inlet	1975	-	1.84	149	2.1	2.3	1.5	0.6	<0.1	4.5
		1976	-	3.38	82	4.1	2.5	2.2	0.2	0.1	4.8
LBWA-5	Boundary Drain	1975	19.6	1.11	124	0.3	2.4	1.6	0.1	0.7	2.2
		1976	23.5	1.28	128	0.4	2.4	1.1	0.4	0.8	3.1
LBWA-6	San Pedro Canal	1975	4.3	0.64	177	0.2	1.5	1.0	0.1	0.4	3.0
		1976	4.5	0.74	195	0.2	1.8	0.9	0.1	0.8	1.1
LBWA-8	West Delta Canal	1975	2.0	0.88	86	0.2	2.3	1.1	0.3	0.8	2.1
		1976	2.9	1.08	112	0.4	1.9	1.0	0.1	0.8	3.2
Outflow:											
LBWA-10	Mud Slough outlet	1975	-	1.16	134	2.4	2.3	1.0	<0.1	<0.1	3.3
		1976	15.5	1.44	151	0.5	2.7	1.5	0.4	0.7	3.2
Internal Stations:											
LBWA-14	Field 37 and 38 discharge	1975	-	1.82	34	1.4	2.6	2.4	0.1	<0.1	5.0
		1976	-	2.41	409	0.9	4.0	3.6	0.4	<0.1	8.2
LBWA-9	Buttonwillow Lake outflow	1975	-	1.39	78	0.2	2.7	2.6	0.1	<0.1	3.0
		1976	-	1.67	49	0.5	2.6	2.6	<0.1	<0.1	5.0
LBWA-12	Ruth Lake lowlift pump	1975	-	1.88	59	1.2	2.4	2.3	<0.1	<0.1	4.8
		1976	-	1.91	68	1.1	3.0	2.6	0.2	0.1	9.0
LBWA-13	Ruth Lake discharge	1975	-	2.58	57	2.5	2.6	2.4	0.1	<0.1	10.6
		1976	-	2.25	41	1.5	5.4	5.2	0.1	0.1	10.4

* 1975 = May-Oct., 1976 = Apr.-Oct.

† LBWA-11 same as LBWA-2, LBWA-7 same as LBWA-5.

is pumped from Mud Slough at LBWA-12 and its overflow monitored at LBWA-13 is discharged into surrounding marshland habitat. As in any use of water (municipal, irrigated croplands, irrigated pastures, flooded duck ponds, etc.) there is a certain degree of water quality degradation as noted by the comparison of LBWA-12 and LBWA-13. However, since the overflow volume is much smaller than the inflow, the mass emission of pollutants is small to nil in the case of Ruth Lake as well as others in this wildlife refuge.

The Los Banos Wildlife Area, in the opinion of the authors, is contributing to the abatement of water pollution by reusing irrigation return flows from croplands and pasture lands. Sediments and nitrate loads are reduced due respectively to sedimentation and nutrient uptake by aquatic and terrestrial vegetation. Similar conclusions may be reached for other wastewater reuses such as in the 202 km^2 (50,000 ac) Grassland Water District located in this immediate vicinity. Moreover, thereare some economic and social benefits derived from the use of return flows.

SPECIAL STUDIES

This portion of the report contains several special study projects conducted in rice fields in Glenn-Colusa Irrigation District, a furrow-irrigated tomato field in Panoche Water District, a tile-drained farm in Panoche Water District, and appraisals on the economics of irrigation and recycle systems.

Flooded Rice Culture

Paddy rice is a major crop in the Sacramento Valley and, to some extent, for the lower (northern) San Joaquin River Basin. About 1,210 to 2,020 km^2 (0.3 to 0.5 million ac) of rice is grown in California, depending upon marketplace considerations. For the Sacramento River Basin, more water is diverted to rice fields than for other crops and they are the largest contributor to irrigation return flows. Although the consumptive water use by rice plants is similar to other crops, more water is diverted because of the more or less continuous flooding and spilling.

Figure 19 gives a location map of the six commercial rice fields in GCID that were intensively monitored in 1975 and 1976 for water flows and water quality. These fields ranged from 0.20 to 0.62 km^2 (50 to 153 ac) in area. Figure 20 gives a plot of weekly water inflows and outflows for Field No. 8, a 0.57 km^2 rice field near Willows. Inflow was continuously monitored by a Hersey-Sparling totalizing meter while outflow was continuously monitored with a 90° v-notch weir and a Leopold-Stevens water stage recorder. Table 24 contains a summary of seasonal quantities of water for six fields, two of which were monitored in both 1975 and 1976. ET was estimated from Class A pan data and seepage losses were obtained by difference. Table 24 shows that water delivered to rice fields varied widely from 1.9 to 3.7 m^3/m^2 (6.2 to 12.1 ac-ft/ac) while surface runoff varied less widely from 0.2 to 0.7 m^3/m^2 (0.7 to 2.3 ac-ft/ac), except for Field No. 16. The fate of water applied to rice fields are mainly ET and seepage losses while outflow varies from 6 to 30%, except for Field No. 16.

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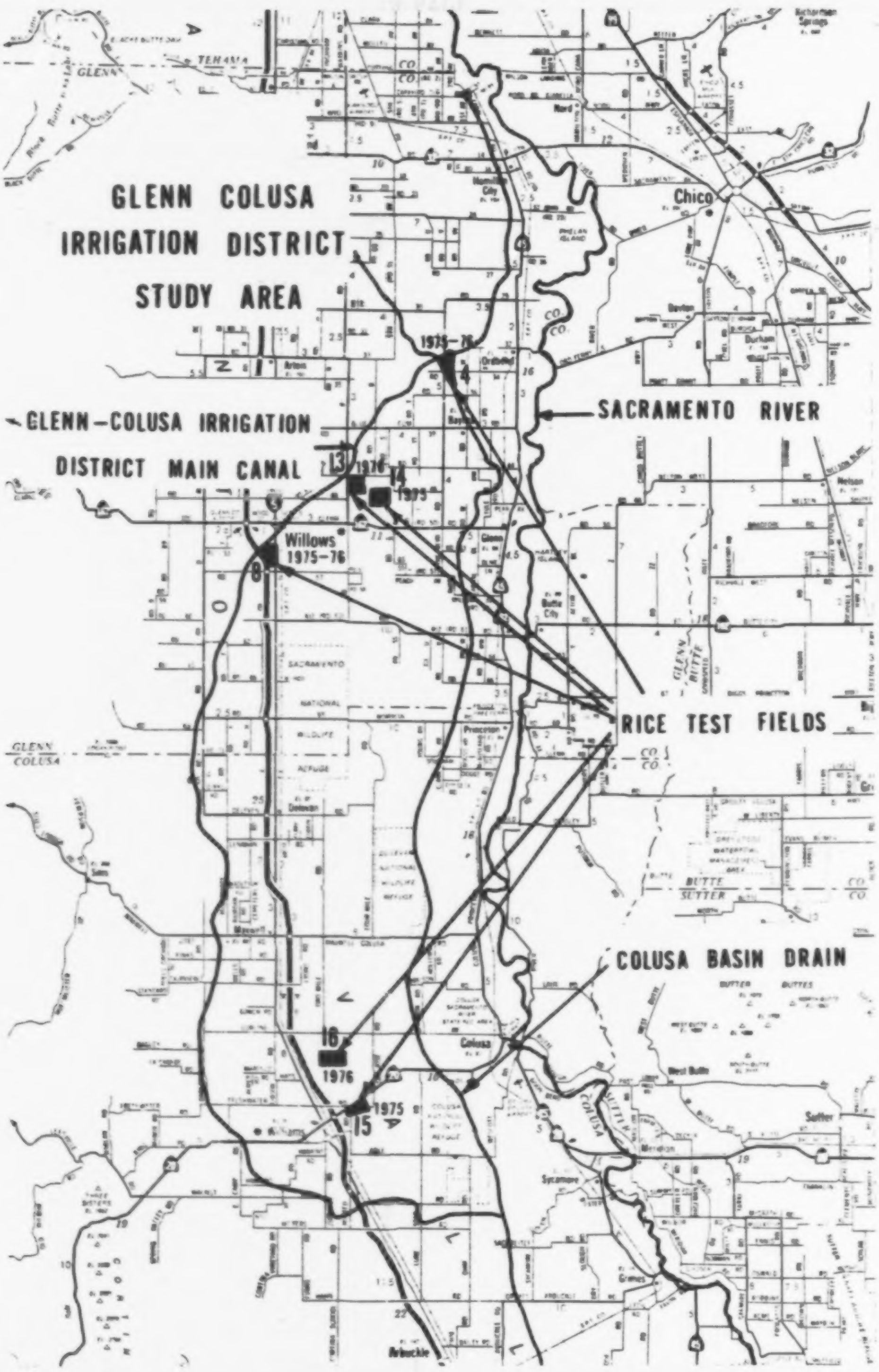
GLENN COLUSA IRRIGATION DISTRICT STUDY AREA
GLENN-COLUSA IRRIGATION DISTRICT MAIN CANAL
SACRAMENTO RIVER
RICE TEST FIELDS
COLUSA BASIN DRAIN
TEHAMA
GLENN
COLUSA
BUTTE
SUTTER
Chico
Durham
Dayton
Ord Bend
Willows
Glenn
Butte City
Princeton
Delevan
Maxwell
Colusa
Meridian
Sycamore
Grimes
Arbuckle
Sutter
West Butte
Nelson
Artois
SACRAMENTO NATIONAL WILDLIFE REFUGE
4
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Figure 19. Location map for monitored rice fields in Glenn-Colusa Irrigation District.

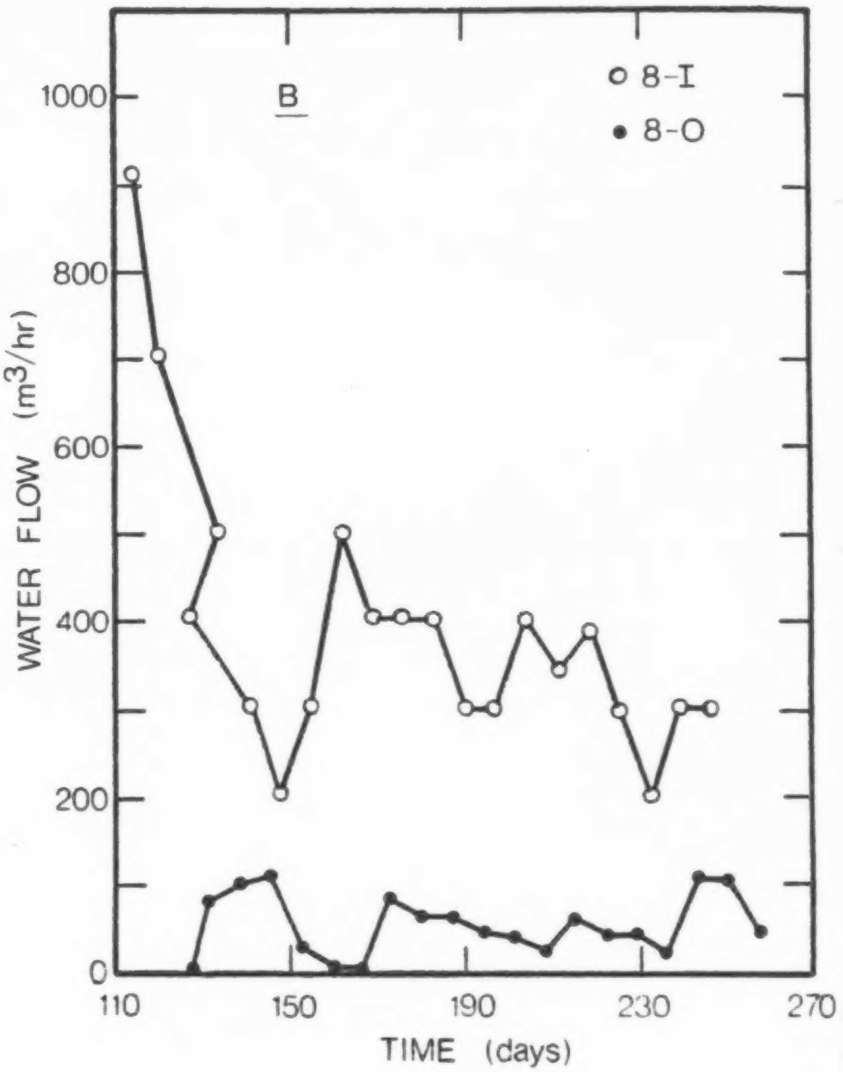

Figure 20. Plot of weekly water inflow and outflow from Rice Field No. 8.

Table 25 contains a similar summary on seasonal quantities of SS. The concentration of SS in the irrigation water for some fields was much higher than the 12 to 24 mg/l for GCID's supply monitoring station (Table 7) because of either reuse of turbid supply water from channels serving dual purposes of supply and drain or erosion in the on-farm delivery ditches. The concentrations of SS in the surface runoffs, however, were uniformly low, except for Field No. 4 in 1975. When the data are examined in terms of unit mass inflow and outflow, only 7 to 34% of SS brought in with the irrigation water is discharged. In other words, flooded rice fields act as settling basins for sediments. Table 26 presents additional water quality. The turbidity data confirms the SS data presented in Table 25. With slight increase for

TABLE 24. SUMMARY OF SEASONAL QUANTITIES OF WATER IN COMMERCIAL RICE FIELDS

Year	1975				1976				
Field number	4	8	14	15	4	8	13	16	Ave.
Surface inflow, m^3/m^2	2.43	2.08	1.91	3.73	3.27	1.90	2.72	3.16	2.65
Precipitation, m^3/m^2	0.08	0.08	0.08	0.08	0.06	0.06	0.06	0.06	0.07
Evapotranspiration, m^3/m^2	1.03	1.03	1.03	1.03	1.12	1.12	1.12	1.12	1.06
Seepage, m^3/m^2	1.22	0.77	0.39	2.04	2.01	0.37	1.43	0.73	1.12
Surface outflow, m^3/m^2	0.26	0.36	0.57	0.74	0.20	0.47	0.23	1.37	0.52
Surface outflow, % of inflow	11	17	30	20	6	25	8	43	20

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TABLE 25. SUMMARY OF SEASONAL QUANTITIES OF SS IN COMMERCIAL RICE FIELDS

Field No.	1975				1976				
	4	8	14	15	4	8	13	16	Ave.
SS in inflow, mg/ℓ	147	20	18	75	13	89	10	13	48
SS in inflow, tons/km^2	357	42	34	279	43	25	27	41	106
SS in outflow, mg/ℓ	138	14	18	27	14	9	18	10	31
SS in outflow, tons/km^2	37	5	10	20	3	4	4	14	12
SS in outflow, % of inflow	10	12	29	7	7	16	15	34	11

TABLE 26. FLOW-WEIGHTED AVERAGE WATER QUALITY IN MONITORED RICE FIELDS

		EC (mS/cm)	Turbidity (JTU)	Total N	Org. N	NH_4	NO_3
				(mg N/ℓ)			
1975 irrigation season:							
Field 4,	inflow	0.10	16	1.02	0.94	0.04	0.02
	outflow	0.09	28	2.31	2.17	0.05	0.06
Field 8,	inflow	0.17	20	1.12	1.00	0.03	0.07
	outflow	0.16	5	1.81	1.60	0.12	0.05
Field 14,	inflow	0.14	13	1.08	1.02	<0.01	0.04
	outflow	0.22	9	1.95	1.85	0.07	0.05
Field 15,	inflow	0.38	31	1.54	1.22	0.11	0.19
	outflow	0.52	10	1.36	1.12	0.21	0.01
1976 irrigation season:							
Field 4,	inflow	0.12	9				
	outflow	0.12	4				
Field 8,	inflow	0.12	12				
	outflow	0.18	9				
Field 13,	inflow	0.13	7				
	outflow	0.14	16				
Field 16,	inflow	0.36	22				
	outflow	0.48	11				

some, the EC values of discharge were similar to those of supply water. These discharges are mainly surface runoffs. N data will be discussed in the next paragraph.

An intensive monitoring program on nitrogen was conducted in four rice fields during the 1975 irrigation season (Wagenet, 1975). Nitrogen species were determined in water samples obtained at the inflow and outflow points, in floodwaters, and in the soil solution (seepage water) with suction probes. Soil samples were also analyzed to the 1 m (3 ft) depth. Prior to planting and flooding, rice growers applied and soil incorporated from 11.2 to 23.5 g/m^2 (100 to 210 lbs N/ac) in the form of ammonium sulfate, urea or N-aqua (aqua NH_3). Field No. 15 was the only field receiving a top dressing of 3.5 g/m^2 (31 lbs N/ac) of ammonium sulfate through aerial broadcast over the flooded field. For illustrative purposes, Figures 21 and 22 show the weekly concentrations of nitrate and ammonium in the flood waters of the rice field at the inflow and outflow points while Figure 23 shows the weekly concentration of organic N in filtered and unfiltered water samples from the outflow point. The predominant N species found was dissolved organic N (see also Table 26). Although NH_4 and NO_3 were at elevated concentration levels shortly after fertilization and flooding, they are considered to be comparatively low. Figure 24 shows a plot of NH_4 and total N concentrations in the runoff waters from Field No. 15 just prior to and immediately after the aerial application of 3.5 gm N/m^2 (31 lbs/ac) of ammonium sulfate. Water samples were collected on an hourly basis for two days with an ISCO automatic water sampler, and extended to three-hour intervals for three more days. This intensive sampling gave NO_3^- concentrations that were consistently low but NH_4 and total N were significant. Ammonium sulfate applied on day 198 between 1000 and 1030 hours rapidly dissolved in the flood waters and peak concentrations of NH_4 were reached 20 hours after application and gradually decreased to normal levels

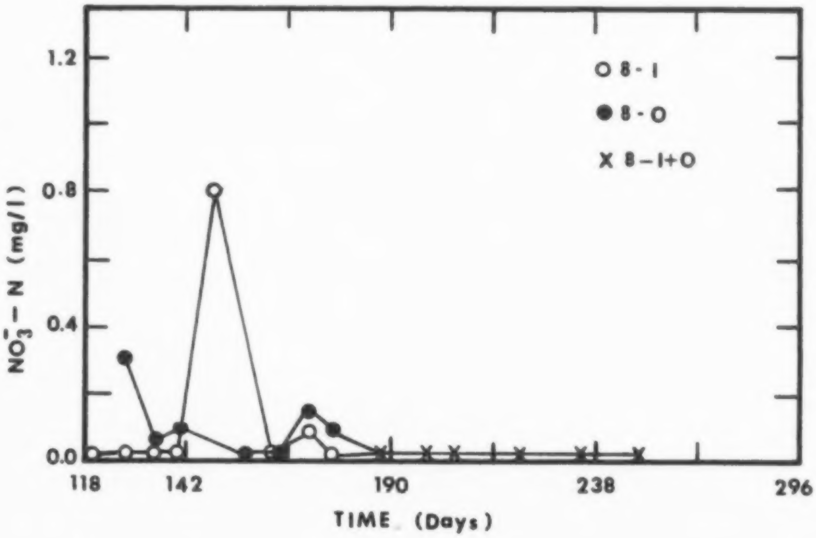

Figure 21. Weekly NO_3-N concentration in flood water of Rice Field No. 8.

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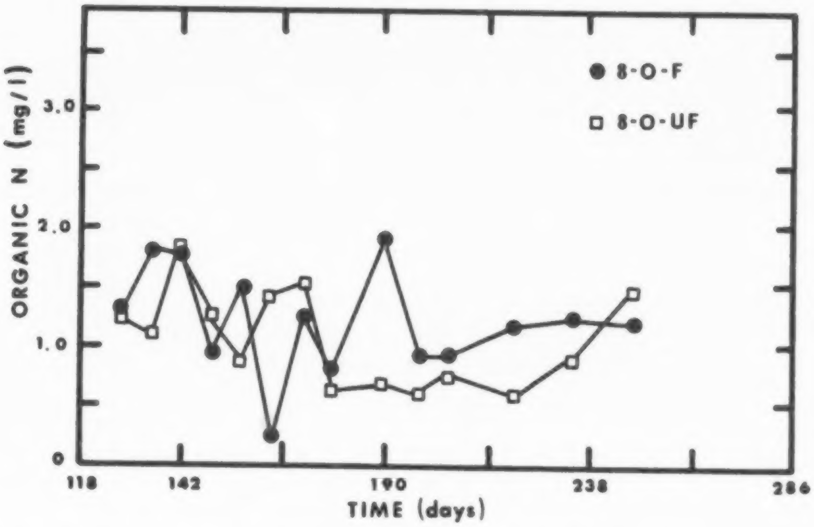

Figure 22. Weekly NH_4-N concentration in flood waters of Field No. 8.

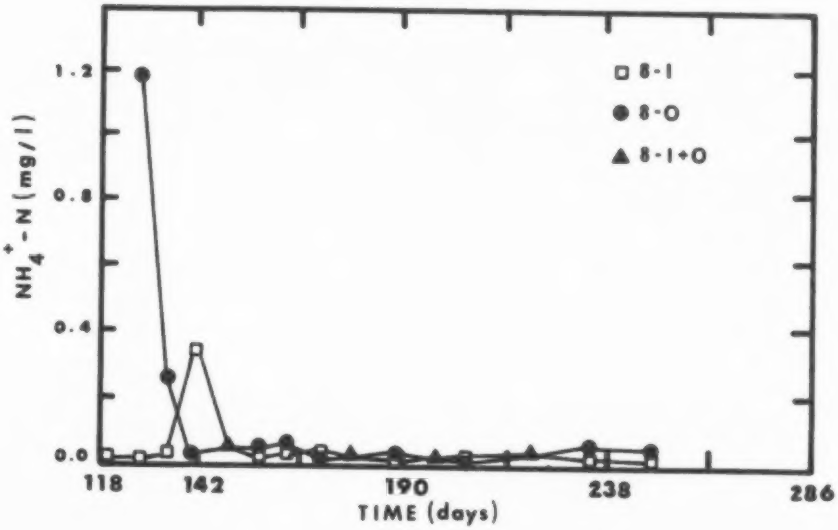

Figure 23. Weekly organic N concentration in filtered (F) and unfiltered (UF) flood waters of Rice Field No. 8.

within five days. This set of data points out that top dressing of N fertilizers may produce a pulse of NH_4 in the discharges and could be minimized if floodwaters are held back for about three days.

A mass balance on N in Field No. 8 was compiled, as indicated in Figure 25. The major inputs of N in this case study is N fertilizer while soil N

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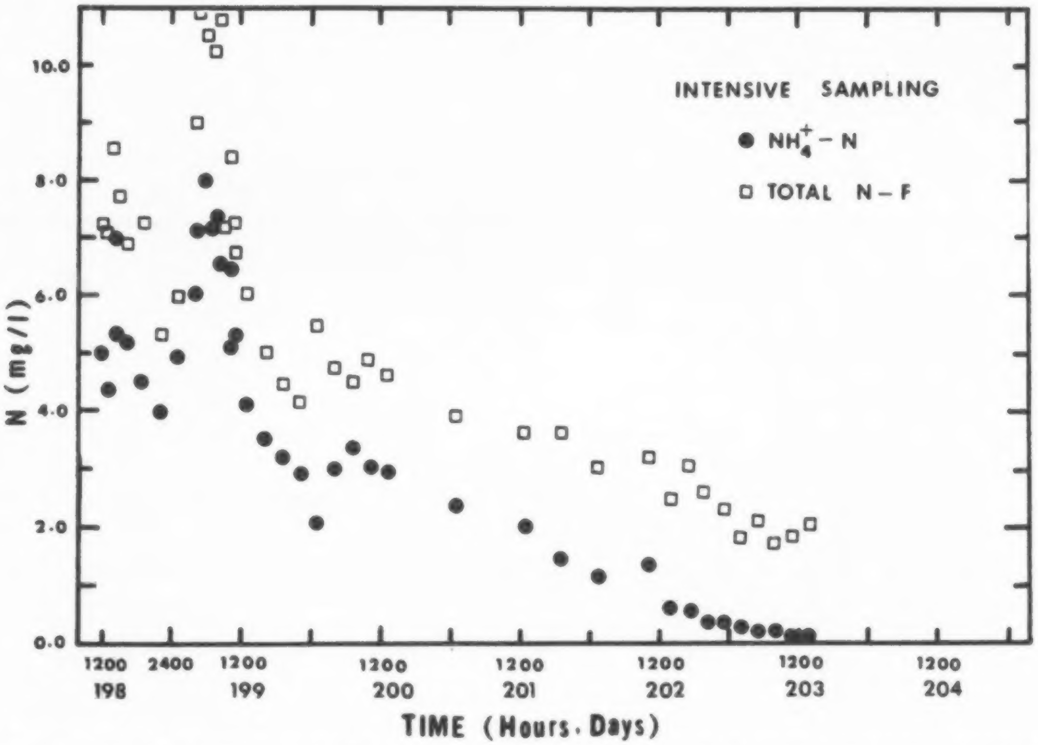

Figure 24. Total N and NH_4-N in intensively sampled drain waters, during and after 35 kg N/ha top dressing of ammonium sulfate in Field No. 15. Symbol F denotes filtered water samples.

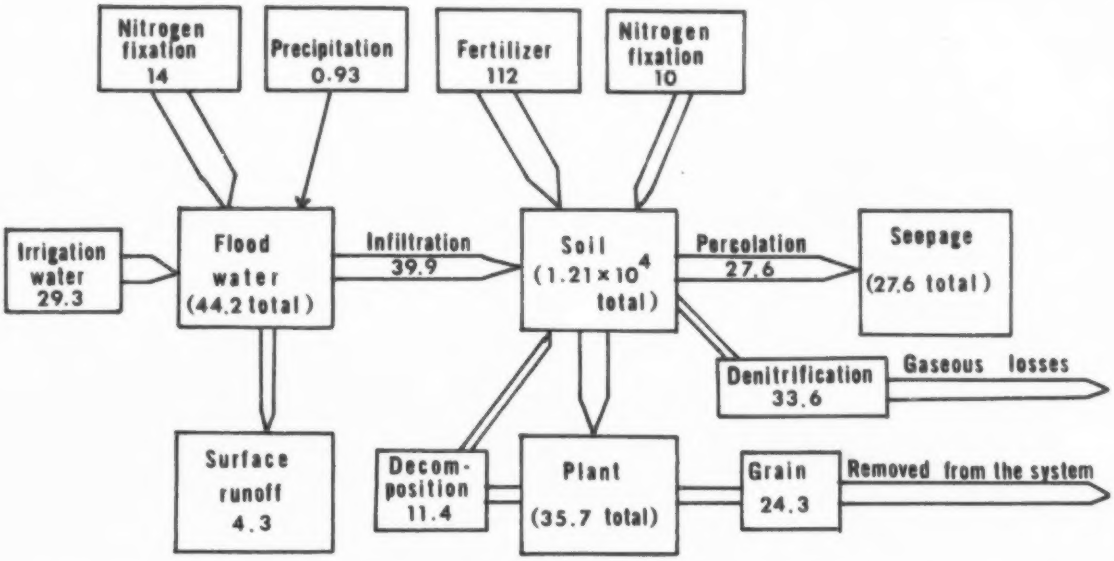
Nitrogen fixation 14
Precipitation 0.93
Fertilizer 112
Nitrogen fixation 10
Irrigation water 29.3
Flood water (44.2 total)
Infiltration 39.9
Soil (1.21 × 10^4 total)
Percolation 27.6
Seepage (27.6 total)
Denitrification 33.6
Gaseous losses
Surface runoff 4.3
Decom-position 11.4
Plant (35.7 total)
Grain 24.3
Removed from the system

Figure 25. Diagrammatic representation of seasonal N flows in kg N/ha in Rice Field No. 8.

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contains a large reservoir of N, only part of which is available to the crop. The outputs of N are almost equally divided among harvested grain, denitrification, and seepage. The mass of N in surface runoff is only about 14% of that N entering this field. Although fertilizer N is about 4.6 times that of the harvested grain, nearly one third was lost through denitrification and another one third to seepage. The seepage and denitrification losses of N are unavoidable in flooded rice culture and it appears that the most viable N management option is to increase the fertilizer use efficiency of the rice plant.

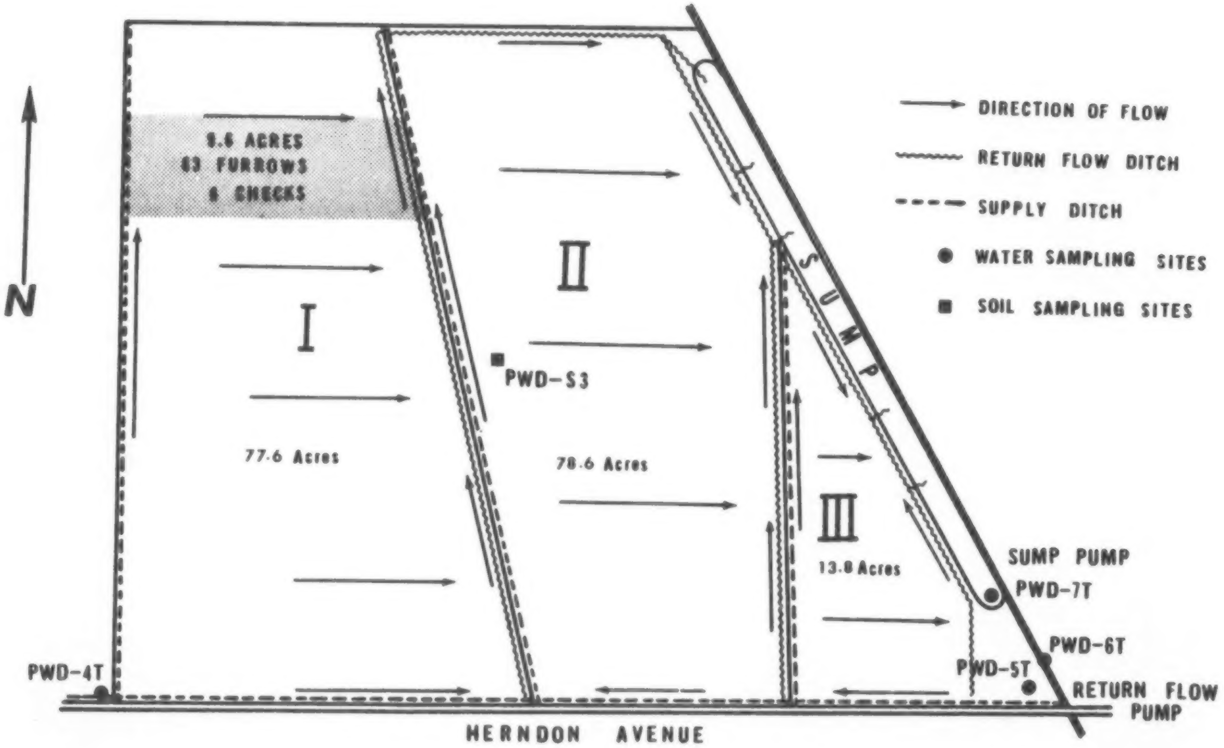
Furrow-Irrigated Tomato Field

A 0.7 km^2 (170 ac) tomato field in Panoche Water District (Figure 15) was studied to obtain information and data on tailwater production and sediment loadings, the use of a tailwater recovery system, and to make economic appraisals of alternative irrigation application methods and tailwater recycle systems. Figure 26 contains a layout of this furrow-irrigated tomato field in 1975. The supply water was obtained from the California Aqueduct through Station PWD-4T and from the Delta-Mendota Canal through PWD-6T. This field was divided into three subfields for cultural operations. The arrows show the direction of water flow for the farm distribution system, the application of waters into furrows, and the collection and reuse of tailwater. Station PWD-7T is located on the return flow sump. All of the tailwater produced in this field was recirculated into subfields II and III.

Table 27 contains the results of a tailwater production test made between July 12-17, 1975 in the 631 x 10^3 m^2 (156 ac) of subfield I and II. During this test period the irrigator applied 35 x 10^3 m^3 (28.54 ac-ft) of water and the tailwater produced was 10 x 10^3 m^3 (8.21 ac-ft), or about 29% of the applied water. The tailwater production was measured at the pump in the return flow ditch.

During this same test period, a more direct measurement on individual furrows was made in a 3.9 x 10^3 m^2 (9.6 ac) portion of subfield I. This subfield contained 36 check dams in the supply ditch. Typically, irrigation water was diverted into 55/65 furrows (four to six checks) at a time using two to three siphons (38 mm or 1-1/2 in diameter) per furrow. The water was applied for about a six- to eight-hour duration per 305 m (1,000 ft) run. Table 28 gives the results for the individual furrow data. The average water application was 95 mm (3.75 in) and average runoff was 23 mm (0.90 in) or 24% of the water applied. The average EC of the tailwater at the end of the furrows was 0.51 mS/cm (0.51 mmhos/cm), slightly greater than the supply water. The increase in salinity is attributed to dissolution of accumulated salts in the furrow beds. In contrast, the average turbidity of 2,240 JTU was 20 times greater than the supply water because of erosion in the furrows. Water was siphoned into furrows at an average rate of 2.33 l/s (37 gpm).

The Panoche soil in this field does not appear to have much aggregation and is highly erodible. It tends to slake upon wetting. The tailwaters produced in this tomato field were completely recirculated. With reduction of water flow velocities and smaller slope in the sump ditch the turbidity of the collected return flows was typically 300 JTU, a substantial reduction due



N
9.6 ACRES
63 FURROWS
6 CHECKS
I
77.6 Acres
II
PWD-S3
78.6 Acres
III
13.8 Acres
SUMP
SUMP PUMP
PWD-7T
PWD-6T
PWD-5T
RETURN FLOW
PUMP
PWD-4T
HERNDON AVENUE
DIRECTION OF FLOW
RETURN FLOW DITCH
SUPPLY DITCH
WATER SAMPLING SITES
SOIL SAMPLING SITES

Figure 26. Layout of furrow-irrigated tomato field with irrigation and tailwater recovery systems, Panoche Water District.

TABLE 27. TAILWATER PRODUCTION TEST IN SUBFIELD I AND II IN THE FURROW-IRRIGATED TOMATO FIELD IN PANOCHE WATER DISTRICT

Description	Surface depth	
	(mm)	(inches)
Irrigation applied	56	2.20
Tailwater produced	16	0.63

TABLE 28. TAILWATER PRODUCTION AND QUALITY TESTS IN INDIVIDUAL FURROWS IN A PORTION OF SUBFIELD I OF THE TOMATO FIELD

Description	Irrigation water	Tailwater
Average surface depth, mm	95	23
Average EC of water, mS/cm	0.41	0.51
Average turbidity of water, JTU	112	2,240

to sedimentation in the sump. Unlike the runoffs from flooded rice fields, the tailwater from this furrow-irrigated tomato field contains a substantial loading of suspended matter. It is clear that the tailwater recovery system for this tomato field contributes to more efficient water use as well as pollution abatement.

Tile-Drained Farm

Another special study conducted in the Panoche Water District was on a 6.78 km^2 (1,675 ac) tile-drained farm (Figure 27). In contrast to the tomato field, this farm extensively reused saline drain waters from Panoche Drain. This farm operator started installing a subsurface drainage system in 1968 to rehabilitate the waterlogged and salt-affected farm. For the first 2.71-km^2 (670 ac) tract in the eastern portion, about 18,810 km (61,700 lineal ft) of 0.15- to 0.3- m (6- to 12- in) concrete tile was installed at 183-m (600-ft) lateral spacing and at a 2.1 m (7 ft) soil depth, and then back-filled with a sand-gravel mix. It had a design capacity of 0.07 m^3/s (2.61 cfs). The tile effluents were collected in a sump at PWD-12E. In 1971, however, a change in the original design was made by substituting 0.1 m (4 in) corrugated plastic for the 0.15-m (6-in) laterals. The recommended spacings were from 73 to 91 m (240 to 300 ft), but the grower used 183-m spacings with an

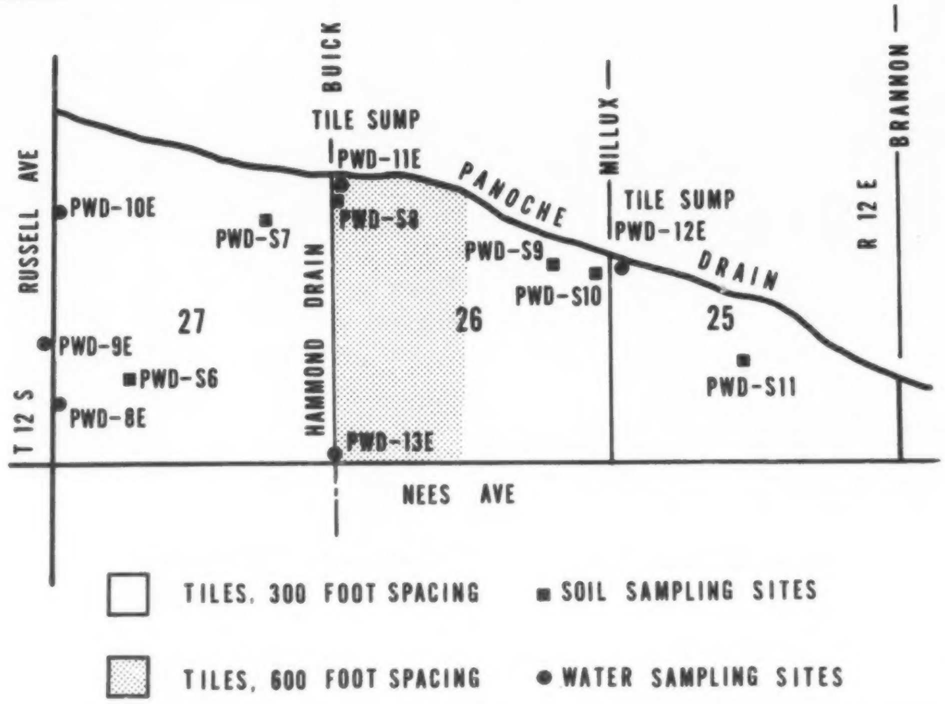

BUICK
TILE SUMP
PWD-11E
PANOCHE DRAIN
MILLUX
TILE SUMP
PWD-12E
BRANNON
R 12 E
RUSSELL AVE
PWD-10E
PWD-S7
PWD-S8
PWD-S9
PWD-S10
27
26
25
PWD-9E
PWD-S6
PWD-8E
T 12 S
HAMMOND DRAIN
PWD-13E
PWD-S11
NEES AVE
TILES, 300 FOOT SPACING
TILES, 600 FOOT SPACING
SOIL SAMPLING SITES
WATER SAMPLING SITES

Figure 27. Map of tile-drained farm in Panoche Water District.

intention of adding another lateral in between after a hydraulic check. More recently, 0.2-m (8-in) corrugated plastic lines are being installed instead of 0.25-m (10-in) concrete baseline tile, and, during the 1975-77 period, the lateral spacing has been reduced to 91 m except for about 1.21 km^2 (300 ac) in the central portion of the farm.

Tile effluents are collected in two sumps, at PWD-12E and -11E, and discharged into the Panoche Drain that collects a mix of surface runoffs and collected subsurface drainage from this farm and others upslope. The grower captures the saline return flow at PWD-10E, mixes it with fresh canal water from PWD-9E, and then uses the blended water for irrigation. Station PWD-8E monitors the mixed supply water. In addition, minor amounts of return flow are also pumped from Hammond Drain at PWD-13E and reused.

Figure 28 contains a histogram of monthly water flows for fresh canal water and mixed supply water, the difference between them being the captured drain water, as well as tile effluents. Also shown in this figure are the planting dates for the major crops. Figures 29 and 30 show the EC and boron concentrations in the various sources of water for this farm. Table 29 presents a summary of the average water quality for the monitored period. The fresh water diverted from the Delta-Mendota Canal is of excellent quality, but is degraded significantly when mixed with the saline drain water. The collected tile effluents are exceedingly high in salinity, seven to eight times more concentrated than the irrigation water, as well as boron, 11 times. The major source of these pollutants is the salt-affected soils.

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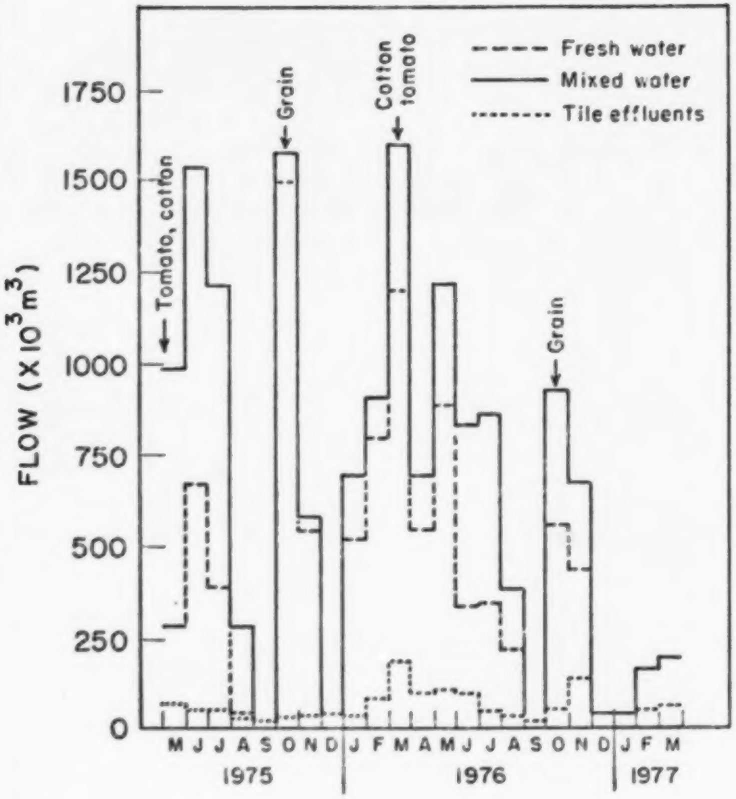

Figure 28. Monthly water flows for the tile-drained farm.

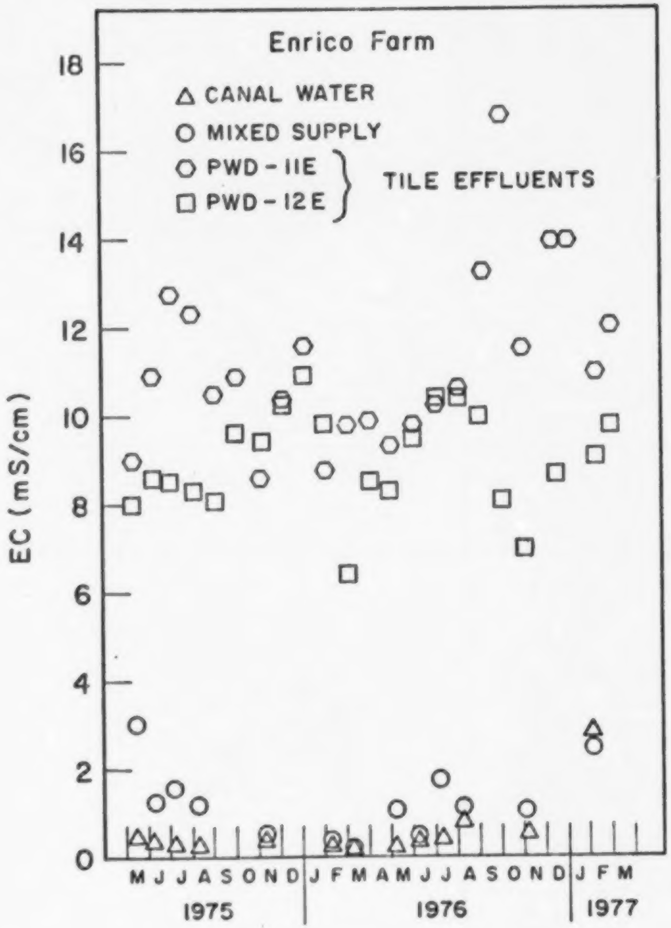

Figure 29. Monthly EC in waters of the tile-drained farm.

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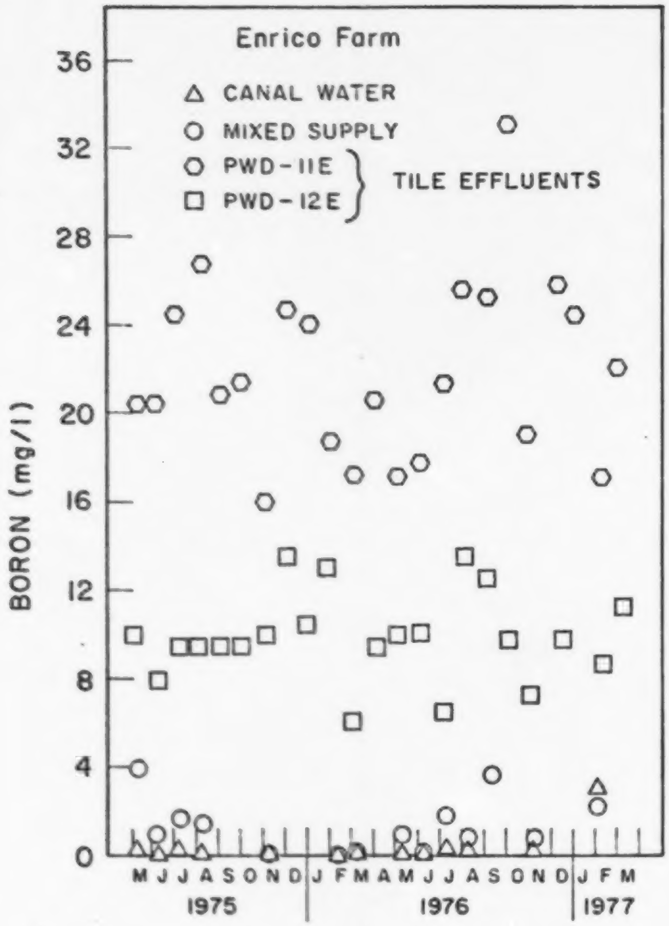

Figure 30. Monthly boron concentrations in waters of the tile-drained farm.

Figure 31 presents three typical soil profiles in this tile-drained farm. PWD-S6 represents salt-free soils, while PWD-S9 and -S10 represent salt-affected soils. PWD-S9 contains excessively high concentrations of EC, boron, and gypsum while PWD-S10 contains lesser amounts of boron. Table 30 gives the mean and standard deviation of the quality parameters for six soil sampling sites. Table 31 shows the impact of these salt-affected soils on the chemistry of tile effluents. The tenfold increase in chloride cannot be wholly attributed to concentration by ET but also leaching of accumulated soil chlorides. The high concentrations of sulfate and calcium are due to the dissolution of gypsum. The high concentrations of sodium as well as sodium adsorption ratio (SAR) are attributed to the displacement of exchangeable sodium by calcium.

Table 32 gives a water balance for this tile-drained farm. It is shown that the mixed supply water consists of a 62 to 38 ratio of fresh to drain waters. The impact on the quality was previously given in Table 29. The

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TABLE 29. FLOW-WEIGHTED AVERAGE WATER QUALITY FOR THE TILE-DRAINED FARM IN THE PERIOD MAY 1975 TO MARCH 1977

Water description	EC (mS/cm)	TDS (mg/ℓ)	B (mg/ℓ)
Fresh canal water	0.35	225	0.1
Captured drain water	2.09	1,380	2.3
Mixed supply water	1.34	860	1.2
Tile effluents	9.21	7,170	13.3

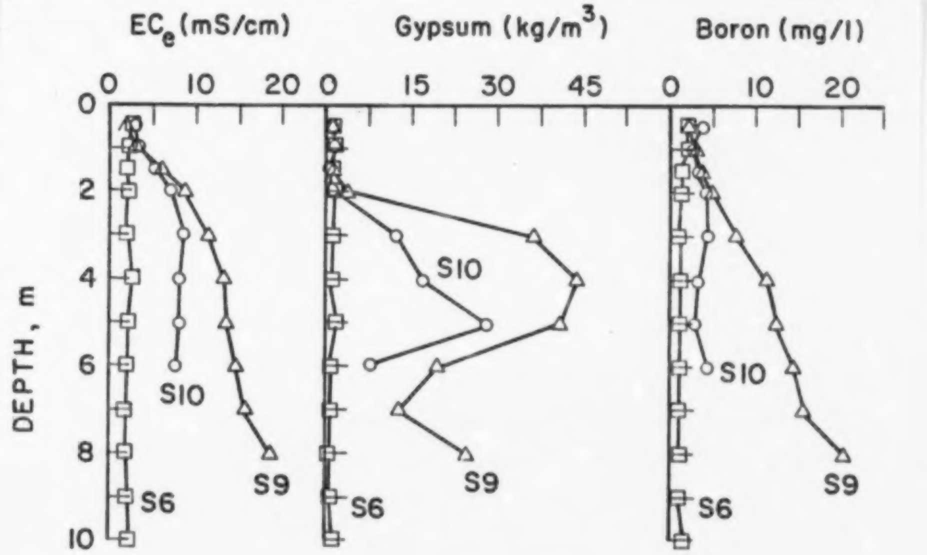

Figure 31. Typical salinity profiles in the tile-drained farm.

total unit water input was 1.41 m^3/m^2 (4.7 ft). Of this input 44% was lost as ET, 7% was recovered as tile effluent, and 49% was attributed to other subsurface losses. The estimate on total ET was obtained from data presented in Table 33. The major summer crops were tomatoes and cotton, and the winter crops were barley and wheat. The ET rates were estimated from evaporation pan data at a nearby location and appropriate crop coefficient.

The yields of crops averaged 2.4 bales/ac for cotton, 0.56 kg/m^2 (2.5 tons/ac) for tomatoes, 0.61 kg/m^2 (2.7 tons/ac) for wheat, 0.56 kg/m^2 (2.5 tons/ac) for barley, and 0.17 kg/m^2 (0.75 tons/ac) for lima beans. All of

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TABLE 30. MEAN AND STANDARD DEVIATION OF SALINITY PARAMETERS FOR SOILS IN TILE-DRAINED FARM

Soil depth		No. of samples	EC_e* (mS/cm)		Estimated† soluble salts (kg/m^3)		Gypsum† (kg/m^3)		Boron‡ (mg/ℓ)	
(m)	(ft)		$\bar{x}$	S_x	$\bar{x}$	S_x	$\bar{x}$	S_x	$\bar{x}$	S_x
0-0.15	0-½	6	3.55	2.66	2.43	1.98	1.52	2.15	2.81	0.84
0.15-0.30	½-1	6	7.11	2.31	2.56	1.73	1.97	2.54	2.83	0.80
0.30-0.46	1-1½	6	4.11	2.47	3.13	2.13	0.79	0.74	2.53	0.88
0.46-0.61	1½-2	6	4.75	2.72	3.76	2.75	1.14	1.51	2.78	1.44
0.61-0.91	2-3	6	6.35	3.89	5.22	3.63	9.96	13.64	3.75	2.49
0.91-1.22	3-4	6	6.72	4.19	5.17	3.69	15.48	18.53	4.27	3.71
1.22-1.52	4-5	6	6.97	3.96	5.40	4.21	15.94	17.27	4.38	4.14
1.52-1.83	5-6	6	7.42	4.49	6.14	5.71	9.02	7.94	5.17	4.79
1.83-2.13	6-7	5	7.55	5.09	6.59	6.61	8.20	17.56	5.83	5.71
2.13-2.44	7-8	4	8.37	7.31	6.52	5.96	10.52	11.79	7.35	8.78
2.44-2.74	8-9	2	4.44	3.48	3.36	2.91	6.44	8.49	3.37	3.44
2.74-3.05	9-10	2	4.74	3.53	4.18	4.03	5.48	6.06	3.95	3.61
3.05-3.35	10-11	2	5.39	3.68	4.55	4.21	8.91	12.10	4.62	3.65
3.35-3.66	11-12	1	4.12	-	2.32	-	0.43	-	5.40	-

*EC_e = electrical conductivity of the saturation extract, $\bar{x}$ = mean, S_x = standard deviation of the mean.

†kg/m^3 = 0.74 tons/ac-ft of soil.

‡mg/ℓ in soil saturation extract.

TABLE 31. TYPICAL CHEMICAL ANALYSES OF WATERS IN THE TILE-DRAINED FARM

Water Type	EC (mS/cm)	SAR* $(mM/\ell)^{1/2}$	Na (mg/ℓ)	Ca (mg/ℓ)	Mg (mg/ℓ)	HCO_3 (mg/ℓ)	Cl (mg/ℓ)	SO_4 (mg/ℓ)
Canal water	0.35	1.4	30	20	10	85	43	34
Surface drain	2.60	6.2	345	140	56	128	337	730
Mixed supply	1.28	3.9	156	90	19	104	142	298
Tile effluents	10.87	16.1	1806	630	200	348	1647	3624
	8.62	11.6	1288	620	200	348	1338	2928

* Sodium adsorption ratio

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TABLE 32. ESTIMATED WATER BALANCE IN THE TILE-DRAINED FARM FOR THE PERIOD MAY, 1975 TO MARCH, 1977

Description	Total volume		Unit volume	
	(10^6 m^3)	(ac-ft)	(m^3/m^2)	(ac-ft/ac)
Fresh canal water	9.29	7,530	0.69	2.28
Captured drain water	5.64	4,575	0.42	1.38
Mixed supply water	14.93	12,105	1.11	3.66
Rainfall	4.08	3,307	0.30	1.00
Total water inputs	19.01	15,412	1.41	4.66
Tile effluents	1.40	1,134	0.10	0.34
Crop evapotranspiration	8.42	6,827	0.63	2.06
Other losses*	9.19	7,451	0.69	2.26

* Deep percolation, fallow ET, interception by open drains, interflow, etc.

TABLE 33. CROPPING AND WATER USAGE IN THE TILE-DRAINED FARM BETWEEN MAY, 1975 AND MARCH, 1977

Crops	1975-77 (10^6 m^2)	1976-77 (10^6 m^2)	Total 1975-77 (10^6 m^2)	ET (m)	Total ET (10^6 m^3)
Summer:					
Tomatoes	2.87	--	2.87	0.70	2.01
Cotton	1.30	2.59	3.89	0.86	3.34
Lima beans	--	1.52	1.52	0.51	0.78
Subtotal	4.17	4.11	8.28		6.13
Winter:					
Barley	--	0.89	0.89	0.45	0.40
Wheat	2.59	1.62	4.21	0.45	1.89
Subtotal	2.59	2.51	5.10		2.29
Grand Total	6.69	6.62	13.31		8.42

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these yields are considered comparable to those grown in comparatively salt-free soils. The main reasons for such high yields in this tract of land appear to be good control on rising water tables with tile drainage and maintaining the surface relatively free of salinity and boron by applying water in excess of crop needs, i.e., about 158% of ET.

Table 34 contains an estimate on salt balance. The salt input through waters was 950 tons/km^2 while output in tile effluents was 816 tons/km^2 or 85% of applied. Because of the large source of salinity in the soil, the amounts of TDS being lost through other subsurface flows (Table 30) are probably an order of magnitude greater.

TABLE 34. ESTIMATED SALT BALANCE IN THE TILE-DRAINED FARM OVER THE MAY, 1975 TO MARCH, 1977 PERIOD

Description	TDS (mg/ℓ)	Water (10^6 m^3)	Mass of TDS (tons)	Unit mass of TDS* (tons/km^2)
Mixed supply water	860	14.93	12,830	946
Rain water	15	4.08	61	4
Total water inputs	-	-	12,891	950
Tile effluents	7,170	1.40	11,060	816

* Based on 6.78 km^2 of total land for two years, or 13.56 km^2.

Economics of Irrigation and Return Flow Recycle Systems

Special studies were conducted to evaluate farm irrigation methods and systems used in the Panoche Water District, which are representative of irrigated agriculture in the west side of the San Joaquin Valley, that would eliminate or substantially reduce the amount of tailwater produced. Based on a 1975 survey (Stewart, 1975) about 80% of irrigated lands in California are irrigated by the furrow or border check-flood method. Significant amounts of tailwater, typically 20 to 40% of that applied, is produced from such surface irrigation methods. A large stream of water is required to reach the lower end of the field as soon as possible to obtain a more uniform water distribution and less deep percolation losses. The installation of a tailwater recovery system, like that in the tomato field in Panoche Water District, would allow maximum stream flow, more uniform water penetration, and higher irrigation efficiency. Most field crops using border or furrow irrigation methods could be irrigated with sprinklers. The latter may require more capital than surface irrigation methods, require less labor, and, with

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good management, will reduce tailwater substantially. For these reasons, the cost analysis for restricting tailwater losses in the tomato field was conducted.

Panoche Water District and others in the trough of the San Joaquin Valley, are faced with rising water tables and associated salinity. These problems complicate the management of irrigation application as well as irrigation return flows. One such illustrative case study was previously reported for a tile-drained farm in Panoche Water District. Using such information and data base, an appraisal was made on the economics of recycling saline drainage water. The analysis is based on a linear programming model that examines optimal cropping pattern and drainage water reuse.

Analysis of Alternative Irrigation Systems

The test case study considered was the 0.69 km^2 (170 ac) tomato field in Panoche Water District (Figure 15) which was furrow irrigated and the tailwater produced was completely recirculated back onto the field. For illustrative purposes, the cost of restricting tailwater losses was estimated by comparing a conventional furrow irrigation system using siphons with three other systems that essentially eliminate tailwater. These three other systems include a furrow irrigated system using gated pipe and tailwater recovery system, a side roll sprinkler system, and a hand move sprinkler system.

Table 35 contains the cost estimates for the four alternative irrigation systems which have been summarized from Tables 36-39. The cost estimates were derived in close consultation with the Manager of the Panoche Water District, and other studies on irrigation costs, for instance, Reed et al. (1976). An 8% interest rate and straight line depreciation was used. Obviously, these cost estimates based on 1976 rates no longer apply to the present because of increased costs on power, interest, materials, etc.

The annual cost of a conventional furrow irrigation system that uses earth-lined head ditches, canvas dams, and 300 38-mm (1-1/2 in) siphons per acre was estimated to be $43,770.87/$km^2$ ($177.21/ac). The field is assumed to be leveled annually and irrigated ten times (including pre-irrigation and seed germination) with 1.52 m^3/m^2 (5 ac-ft/ac) of canal water.

A second furrow irrigation system with gated pipe, tailwater settling (sump) pond, and tailwater reuse sump pump was also analyzed. Total water use is reduced from 1.52 m^3/m^2 to 1.14 m^3/m^2 (3.75 ac-ft/ac) because of tailwater recovery and reuse. This value was obtained from monitoring the tomato field equipped with such a system. The recovered tailwater was 25% of that applied. The annual cost of this second surface irrigation system was estimated to be $37,111.75/$km^2$ ($150.25/ac), slightly less than the conventional one. The investment in the recovery system increased from $1,911.78/$km^2$ ($7.74/ac) to $61503/$km^2$ ($249/ac) but labor decreased from $33,345/$km^2$ ($135/ac) to $22,230/$km^2$ ($90/ac).

The annual cost for a hand move sprinkler system was estimated to be $37,595.87/$km^2$ ($152.21/ac). Although the capital costs of $5,172.18/$km^2$

TABLE 35. SUMMARY OF ANNUAL COST* FOR IRRIGATING THE 0.69 KM^2 TOMATO FIELD IN PANOCHE WATER DISTRICT BY ALTERNATIVE IRRIGATION SYSTEMS.

	Furrow with siphons and no tailwater reuse		Furrow with gated pipes and tailwater reuse		Side roll sprinkler		Hand move sprinkler	
	($\$/km^2$)	($/ac)	($\$/km^2$)	($/ac)	($\$/km^2$)	($/ac)	($\$/km^2$)	($/ac)
Investment	1,911.78	7.74	61,503.00	249.00	71,968.39	291.37	40,972.36	165.88
Depreciation	160.55	0.65	2,462.59	9.97	4,789.33	19.39	2,712.06	10.98
Interest	76.57	0.31	2,460.12	9.96	2,882.49	11.67	1,637.61	6.63
Taxes	39.52	0.16	1,230.06	4.98	1,440.01	5.83	822.51	3.33
Total overhead cost	276.64	1.12	6,152.77	24.91	9,111.83	36.89	5,172.18	20.94
Irrigation preparation	2,657.72	10.76	2,316.86	9.38	-	-	-	-
Water cost	7,410.00	30.00	5,557.50	22.50	5,557.50	22.50	5,557.50	22.50
Labor ($4.50/hr)	33,345.00	135.00	22,230.00	90.00	11,115.00	45.00	22,230.00	90.00
Repairs	81.51	0.33	83.98	0.34	2,877.55	11.65	1,640.08	6.64
Power	-	-	770.64	3.12	2,553.98	10.34	2,309.45	9.35
Lateral installation and removal	-	-	-	-	348.27	1.41	686.66	2.78
Total operating cost	43,494.23	176.09	30,958.98	125.34	22,452.30	90.90	32,423.69	131.27
Total irrigation cost	43,770.87	177.21	37,111.75	150.25	31,564.13	127.79	37,595.87	152.21

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* 1976 rates

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TABLE 36. ANNUAL COST* FOR FURROW IRRIGATING 0.69 KM^2 TOMATO FIELD WITH SIPHONS AND NO TAILWATER RECOVERY

	Depreciable life	Total costs	Investment costs	Annual costs							
				Depreciation		Interest		Taxes		Total	
	(yrs)	($/ac)	($/ac)	($/km^2)	($/ac)	($/km^2)	($/ac)	($/km^2)	($/ac)	($/km^2)	($/ac)
Investment:											
Ditcher (1.37 m or 54 in.)	20	2,100	2.63	32.11	0.13	27.17	0.11	12.35	0.05	71.63	0.29
Siphons (38 mm or 1½ in., 300/ac)	10	475	1.36	34.58	0.14	12.35	0.05	7.41	0.03	54.34	0.22
Canvas (12/ac)	5	350	1.00	49.40	0.20	9.88	0.04	4.94	0.02	64.22	0.26
Ditch closer	15	2,200	2.75	44.46	0.18	27.17	0.11	14.82	0.06	86.45	0.35
Total overhead cost		5,125	7.74	160.55	0.65	76.57	0.31	39.52	0.16	276.64	1.12
Operating Cost:				($/km^2)	($/ac)						
Irrigation preparation											
Fuel and repairs				1,486.94	6.02						
Labor ($0.75/ac)				829.92	3.36						
Total leveling				2,316.86	9.38						
Ditch open and close											
Fuel and repairs				202.54	0.82						
Labor ($0.12/ac)				133.38	0.54						
Total ditch costs				335.92	1.36						
Total irrigation preparation cost				2,657.72	10.76						
Irrigation (10X) cost											
Labor (30 hrs/ac)				33,345.00	135.00						
Water (5 ac-ft/ac)				7,410.00	30.00						
Repairs				81.51	0.33						
Total cost for irrigation				40,836.51	165.33						
Total operating cost				43,494.23	176.09						
Total overhead cost				276.64	1.12						
Total irrigation cost				43,770.87	177.21						

* 1976 costs

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TABLE 37. ANNUAL COST* FOR IRRIGATING 0.69 KM^2 TOMATO FIELD WITH GATED PIPE AND TAILWATER RECOVERY SYSTEM

	Depreciable life	Total costs	Investment costs	Annual costs							
				Depreciation		Interest		Taxes		Total	
	(yrs)	($/ac)	($/ac)	($/km^2)	($/ac)	($/km^2)	($/ac)	($/km^2)	($/ac)	($/km^2)	($/ac)
Investment:											
15 in. PVC pipes	30	10,560	66.00	543.40	2.20	652.08	2.64	326.04	1.32	1,521.52	6.16
10 in. PVC pipes	30	3,300	21.00	172.90	0.70	207.48	0.84	103.74	0.42	484.12	1.96
Gated pipes	30	18,744	117.00	963.30	3.90	1,155.96	4.68	577.98	2.34	2,697.24	10.92
Pump	10	4,000	25.00	617.50	2.50	247.00	1.00	123.50	0.50	988.00	4.00
Settling pond	30	3,250	20.00	165.49	0.67	197.60	0.80	98.80	0.40	461.89	1.87
Total overhead costs		39,854	249.00	2,462.59	9.97	2,460.12	9.96	1,230.06	4.98	6,152.77	24.91

Operating costs:	($/km^2)	($/ac)
Irrigation preparation		
Fuel and repairs	1,486.94	6.02
Labor ($0.75/ac)	829.92	3.36
Total leveling	2,316.86	9.38
Irrigation (10X)		
Labor (20 hrs/ac)	22,230.00	90.00
Water (3.75 ac-ft/ac)	5,557.50	22.50
Power for recirculation	770.64	3.12
Fuel and repairs	83.98	0.34
Total cost for irrigation	28,642.12	115.96
Total operating cost	30,958.98	125.34
Total overhead cost	6,152.77	24.91
Total irrigation cost	37,111.75	150.25

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* 1976 costs

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TABLE 38. ANNUAL COST* FOR IRRIGATING 0.69 KM^2 TOMATO FIELD WITH A SIDE ROLL SPRINKLER SYSTEM

	Depreci-able life	Total costs	Invest-ment costs	Annual costs							
				Depreciation		Interest		Taxes		Total	
	(yrs)	($/ac)	($/ac)	($/km^2)	($/ac)	($/km^2)	($/ac)	($/km^2)	($/ac)	($/km^2)	($/ac)
Investment:											
10 in. aluminum pipes	15	4,642	27.31	449.54	1.82	269.23	1.09	133.38	0.54	852.15	3.45
8 in. aluminum pipes	15	3,478	20.46	335.92	1.36	202.54	0.82	101.27	0.41	639.73	2.59
Hydrant valves	20	535	3.15	39.52	0.16	32.11	0.13	14.82	0.06	86.45	0.35
Pump	15	10,062	62.50	1,029.99	4.17	617.50	2.50	308.75	1.25	1,956.24	7.92
Laterals	15	30,395	178.13	2,934.36	11.88	1,761.11	7.13	881.79	3.57	5,577.26	22.58
Total overhead costs		46,504	291.37	4,789.33	19.39	2,882.49	11.67	1,440.01	5.83	9,111.83	36.89

Operating costs:	($/km^2)	($/ac)
Irrigation (10X)		
Labor (10 hrs/ac)	11,115.00	45.00
Water (3.75 ac-ft/ac)	5,557.50	22.50
Power	2,553.98	10.34
Repairs (4%)	2,877.55	11.65
Total cost for irrigation	22,104.03	89.49
Lateral installation and removsl		
Fuel and repairs	175.37	0.71
Labor	172.90	0.70
Total lateral installation and removal	348.27	1.41
Total operating cost	22,452.30	90.90
Total overhead cost	9,111.83	36.89
Total irrigation cost	31,564.13	127.79

* 1976 costs

TABLE 39. ANNUAL COST* FOR IRRIGATING 0.69 KM^2 TOMATO FIELD WITH A HAND MOVE SPRINKLER SYSTEM

	Depreci-able life	Total costs	Invest-ment costs	Annual costs							
				Depreciation		Interest		Taxes		Total	
	(yrs)	($/ac)	($/ac)	($/$km^2$)	($/ac)	($/$km^2$)	($/ac)	($/$km^2$)	($/ac)	($/$km^2$)	($/ac)
Investment:											
10 in. aluminum pipes	15	4,612	27.31	449.54	1.82	269.23	1.09	135.85	0.55	854.62	3.46
8 in. aluminum pipes	15	3,478	20.46	335.92	1.36	202.54	0.82	101.27	0.41	639.73	2.59
Hydrant valves	20	814	4.79	59.28	0.24	46.93	0.19	24.70	0.10	130.91	0.53
Pump	15	10,062	62.50	1,029.99	4.17	617.50	2.50	308.75	1.25	1,956.24	7.92
Laterals	15	8,639	50.82	837.33	3.39	501.41	2.03	251.94	1.02	1,590.68	6.44
Total overhead costs		27,605	165.88	2,712.06	10.98	1,637.61	6.63	822.51	3.33	5,172.18	20.94
Operating costs:				($/$km^2$)	($/ac)						
Irrigation (10X)											
Labor (20 hrs/ac)				22,230.00	90.00						
Water (3.75 ac-ft/ac)				5,557.50	22.50						
Power				2,309.45	9.35						
Repairs (4%)				1,640.08	6.64						
Total cost for irrigation				31,737.03	128.49						
Lateral installation and removal											
Fuel and repairs				345.80	1.40						
Labor				340.86	1.38						
Total lateral installation and removal				686.66	2.78						
Total operating cost				32,423.69	131.27						
Total overhead cost				5,172.18	20.94						
Total irrigation cost				37,595.87	152.21						

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[*] 1979 costs

($20.94/ac) were less than the gated pipe-reuse system, the operating costs of \$32,423.69/km^2 (\$131.27/ac) were slightly higher.

The side roll sprinkler system was the least cost system with an annual cost of \$31,564.13/km^2 (\$127.79/ac). The capital costs of \$9,111.83/km^2 (\$36.89/ac) were higher as compared to the other systems but only 247 hours of labor (1 hr/ac) per irrigation is needed to operate this system and therefore the labor costs are considerably less.

Fereres et al. (1979) have made similar irrigation cost estimates by assuming a 0.65 km^2 field supplied by water from a well having a 32.8-m (100-ft) pumping lift, 1.07 m^3/m^2 (3.5 ac-ft/ac) for surface irrigation and 0.91 m^3/m^2 (3.0 ac-ft/ac) for sprinkler system, and irrigation applied from six to eight times. Annual cost for furrow irrigation of a field crop with tailwater recovery system was estimated to be \$35,728.55/km^2 (\$144.65/ac), which is slightly less than estimated in Table 27. Annual costs for irrigating with hand move and wheel line sprinklers were estimated to be \$46,349.55/km^2 (\$187.65/ac) and \$41,533.05/km^2 (\$168.15/ac), respectively. The significant differences between estimates of the authors (1976) and Fereres et al. (1979) are attributed mainly to higher cost estimates in overhead and power.

The data presented in Table 35 indicate that sprinkler irrigation systems can reduce tailwater and costs less than surface methods for 1976 but may not be valid today due to changes in energy costs. The use of a tailwater recovery system for furrow irrigated fields appears to have some advantage over those without tailwater reuse. The assumed cost of water used in this analysis was \$4.86 per 10^3 m^3 (\$6.00/ac-ft). The higher the cost of water, the greater will be the cost savings from using the more efficient irrigation systems.

The internal rate of return, r, was approximated for the three irrigation systems capable of reducing tailwater production using an iterative method involving

$$r = \frac{\text{Annual Net Return}}{\text{Capital Cost}} \left[1 - \frac{1}{(1 + r)^n} \right]$$

where n is the number of iterations. Savings in annual irrigation costs for the three systems was used as the annual net return. The internal rate of return for the furrow irrigated-reuse system was about 18%, the side roll sprinkler system, 16%, and the hand move sprinkler system, 16.5%. The investment in more efficient irrigation systems appears to be more profitable.

Analysis on Drainage Water Management

The test case considered was the 6.78 km^2 (1,675 ac) tile-drained farm in Panoche Water District (Figure 15), which has been recycling a mixture of surface runoff and tile drainage effluent since 1969. A normative linear programming (LP) analysis was developed based on the operation of this farm. The objective of the LP problem is a cropping pattern that maximizes returns

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to land and management for the farm subject to restraints on crop rotation, quantity and quality of applied water, and resource availability.

In this farm, the quality of the applied water is controlled by varying the proportions of fresh canal water and saline captured drain water. This farm is entitled to 6.20 x 10^6 m^3 (5,026 ac-ft) of district canal water. The grower captures drain water and mixes it with fresh water. The farm has access to drainage water from within the farm as well as upslope irrigations collected in the Panoche Drain. The LP model was run with a range of zero to 3.70 x 10^6 m^3 available drain water in the Panoche Drain.

Gross revenues for cropping activities were determined using area average prices and yields from the period 1970 to 1976. Net revenues were then derived by subtracting typical production costs obtained from private communication with the University of California Cooperative Extension Service (1976). Water activities were defined for several combinations of project (fresh) and recycled drain water. The costs of these activities were treated as cost in the objective function. The cost of pumping return flows back to the field was assumed to be \$2.84 per 10^3 m^3 (\$3.50/ac-ft). Several solutions were derived for district water prices of \$4.05 per 10^3 m^3 (\$5/ac-ft) and \$16.20 per 10^3 m^3 (\$20/ac-ft).

Crop alternatives included tomatoes, wheat, cotton, alfalfa seed, sugar beets, and dry beans. These crops were separated into three classes according to yield tolerance to boron concentration in the applied water (Ayers and Westcot, 1976). For each boron tolerance level, limits are set on the proportion of captured drain water in the applied water to avoid yield reductions, i.e., high, medium, and low quality blends. These limits are based on the flow-weighted average boron concentrations reported earlier, i.e., 0.1 mg/l for canal water and 2.5 mg/l for drain water. Although the concentration of TDS was about 860 mg/l it does not appear to be detrimental to the above mentioned crops. Therefore, the quality constraint in the applied mixed water is boron and not TDS. Solutions were also derived using an assumed boron concentration of 10 mg/l in the collected and reused tile effluents. Water application and runoff rates were based on values estimated by the California Department of Water Resources (1975). Maximum crop land area restrictions were included to reflect rotational and crop control requirements.

Tables 40 and 41 contain the computed optimal project and drain water reuse, cropping patterns, and net returns for three levels of drain water availability and two levels of project water price. For the case of assumed current district water price of \$4.05 per 10^3 m^3 (\$5/ac-ft) and availability of 3,700 x 10^3 m^3 (3,000 ac-ft) of drain water in Panoche Drain, drain water recycling amounted to 68% of the total applied water. As availability of drain water decreased to 1,234 x 10^3 m^3 (1,000 ac-ft) and zero m^3, the percentage of drain water recycling decreased with a corresponding increase in fresh water use; i.e., 57 and 37%, respectively. The average returns, however, were not changed significantly, \$82,992 to \$82,498 per km^2 (\$336 to \$334 per ac) because of shifts in cropping pattern. For the high drain water usage, the boron sensitive dry bean are not planted (Table 40).

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TABLE 40. OPTIMAL CROPPING PATTERN AND DRAINAGE WATER USE FOR THREE LEVELS OF DRAIN WATER AVAILABILITY FOR THE 6.78 KM^2 TILE-DRAINED FARM WITH CURRENT (1976) DISTRICT WATER COST OF \$4.05 PER 10^3 M^3 (\$5 PER AC-FT)

Water Volume:	$10^3 m^3$	ac-ft	$10^3 m^3$	ac-ft	$10^3 m^3$	ac-ft
Available drain water	3,700	3,000	1,234	1,000	0	0
Drain water use						
High quality blend	1,234	1,000	781	633	0	0
Medium quality blend	2,192	1,777	2,192	1,777	1,739	1,410
Low quality blend	746	605	469	380	469	380
Total drain water use	4,172	3,382	3,441	2,790	2,208	1,790
Percent of total applied water	68	68	57	57	37	37
Drain water discharged	1,681	1,363	0	0	0	0
Project water use						
High quality blend	1,234	1,000	1,937	1,570	2,717	2,203
Medium quality blend	645	523	645	523	1,098	890
Total project water use	1,879	1,523	2,582	2,093	3,815	3,093
Total applied water	6,050	4,905	6,023	4,883	6,023	4,883
Cropping Pattern:	$10^3 m^2$	ac	$10^3 m^2$	ac	$10^3 m^2$	ac
Tomatoes	2,024	500	2,024	500	2,024	500
Wheat	2,428	600	2,428	600	2,428	600
Cotton	1,619	400	1,619	400	1,619	400
Alfalfa seed	304	75	0	0	0	0
Sugar beets	405	100	405	100	405	100
Dry beans	0	0	304	75	304	75
	6,779	1,675	6,779	1,675	6,779	1,675
Returns:	\$82,992/km^2	\$336/ac	\$82,745/km^2	\$335/ac	\$82,498/km^2	\$334/ac

TABLE 41. OPTIMAL CROPPING PATTERN AND DRAINAGE WATER USE FOR THREE LEVELS OF DRAIN WATER AVAILABILITY FOR THE 6.78 KM^2 TILE-DRAINED FARM WITH ASSUMED DISTRICT WATER COST OF $16.20 PER 10^3 M^3 ($20 PER AC-FT

Water Volume:	$10^3 m^3$	ac-ft	$10^3 m^3$	ac-ft	$10^3 m^3$	ac-ft
Available drain water	3,700	3,000	1,234	1,000	0	0
Drain water use						
High quality blend	1,234	1,000	1,359	1,101	1,359	1,101
Medium quality blend	1,442	1,169	1,615	1,309	381	309
Low quality blend	2,690	2,180	469	380	469	380
Total drain water use	5,366	4,349	3,443	2,790	2,209	1,790
Percent of total applied water	76	76	57	57	37	37
Drain water discharged	489	396	0	0	0	0
Project water use						
High quality blend	1,234	1,000	1,359	1,101	1,359	1,101
Medium quality blend	424	344	1,223	991	2,457	1,991
Total project water use	1,658	1,344	2,582	2,092	3,816	3,092
Total applied water	7,025	5,693	6,024	4,882	6,024	4,882
Cropping Pattern:	$10^3 m^2$	ac	$10^3 m^2$	ac	$10^3 m^2$	ac
Tomatoes	2,024	500	2,024	500	2,024	500
Wheat	2,428	600	2,428	600	2,428	600
Cotton	1,619	400	1,619	400	1,619	400
Alfalfa seeds	304	75	0	0	0	0
Sugar beets	405	100	405	100	405	100
Dry beans	0	0	304	75	304	75
Total	6,779	1,675	6, 779	1,675	6,779	1,675
Returns:	$79,534/$km^2$	$322/ac	$78,052/$km^2$	$316/ac	$75,582/$km^2$	$306/ac

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If a \$16.21 per 10^3 m^3 (\$20/ac-ft) district water cost were assumed, the amount of drain water reuse would increase from 68% to 76% (Table 41) blend in the applied water for the case of 3,700 x 10^3 m^3 (3,000 ac-ft) drain water availability. At this higher cost of fresh water, however, the percentages of drain water use for the lower drain water availabilities did not differ from lower cost. It should be noted that although the maximum drain water available is assumed to be 3,700 x 10^3 m^3 (3,000 ac-ft), greater amounts were recycled because of the unique nature of the farm recycle system, i.e., drain water generated from a preceding irrigation in the farm may be used for the subsequent irrigation. The average returns in Table 41 are smaller than those in Table 40 as a result of the higher cost of canal water and the change in cropping pattern from wheat to alfalfa seed which has a higher tolerance for boron. For the 3,700 x 10^3 m^3 (3,000 ac-ft) drain water availability case, project water usage decreased from 1,879 to 1,658 x 10^3 m^3 (1,523 to 1,344 ac-ft), but additional total water was required to grow the alfalfa seed that replaced wheat in the optimal cropping pattern. On the other hand, if external drain water supply is decreased below 3,700 x 10^3 m^3 (3,000 ac-ft), changes in project water costs do not affect the amount of drain water reuse.

These two special economic studies indicate the complexity of evaluating tailwater production and drain water reuse. The amount of tailwater produced can be reduced significantly and the annual costs of irrigation can be reduced slightly by adopting either tailwater recovery system for the furrow irrigation system or switching to sprinkler system. However, the high capital requirements may constrain adopting more efficient irrigation systems. For example, the costs of installing a furrow irrigation in the 0.69 km^2 (170 ac) tomato field is only \$5,125 as compared to \$39,854 for adding a tailwater recovery system to furrow irrigation, \$46,504 for a side roll sprinkler system, and \$27,605 for a hand move sprinkler system. Although the annual irrigation costs are lowered in the more efficient systems, the purchase of such systems may not be the optimal investment if capital is limited. Greater returns may be realized from investment in land or machinery. It is clear that in 1976 there was no economic incentives to adopt more efficient irrigation systems. However, if water prices and power were increased, more efficient use of water may result.

The profitability of augmenting the fresh water supply with poorer quality drain water depends on the costs of both district water and recycle system. It was shown that with a higher cost of irrigation water the greater is the value of the drainage water. In the case study on the tile-drained farm, the optimal water supply consists of 76% drain water for water price of \$16.20/10^3 m^3 (\$20/ac-ft) and 68% for price of \$4.05/10^3 m^3 (\$5/ac-ft). If growers reuse more drainage water at farm sites, the quantity of return flow available for reuse for downstream water users would be reduced and have significant impacts on those who rely heavily on return flows. However, if water use efficiency is improved with recirculation, fresh water saved would become available for possible redistribution.

IRRIGATION TAILWATER QUANTITY AND QUALITY

Figure 32 gives a schematic representation on the fate of water diverted by irrigated agriculture from a given reach of a river system. This figure

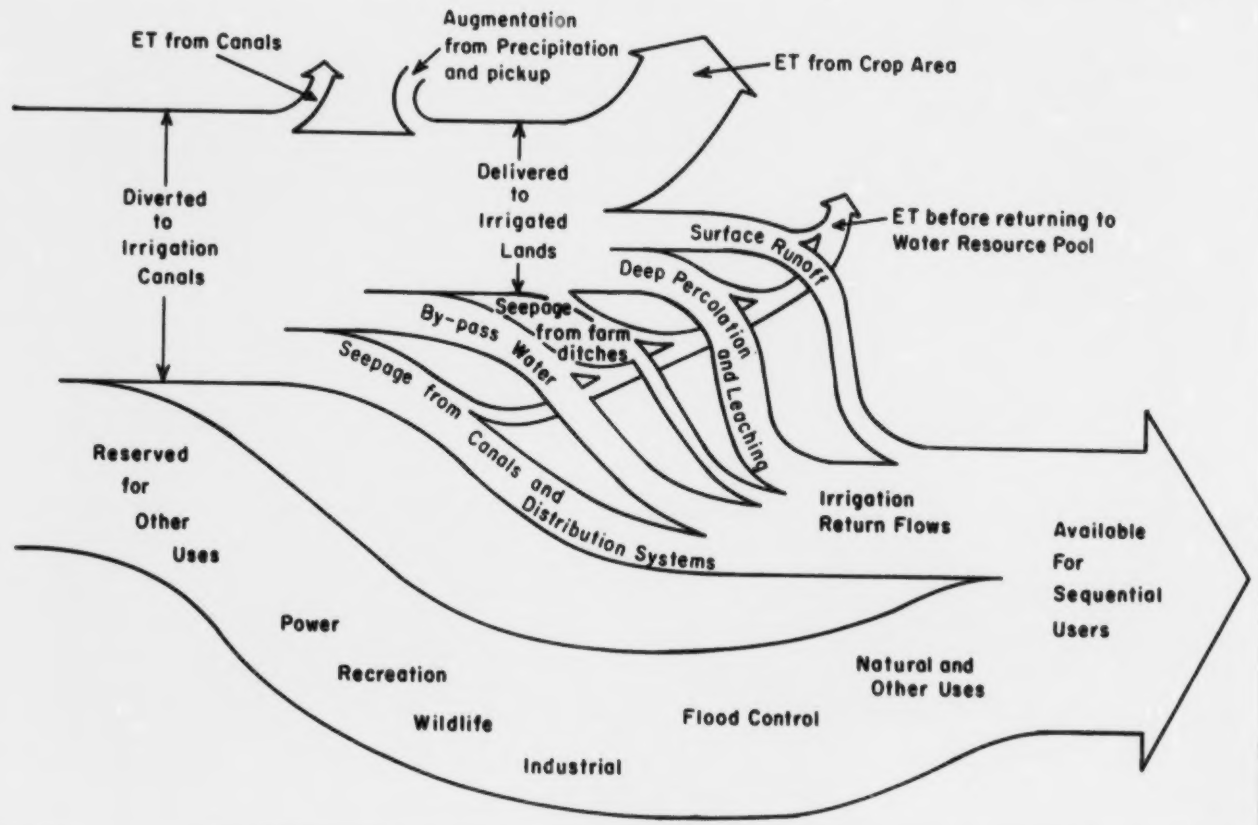
ET from Canals
Augmentation from Precipitation and pickup
ET from Crop Area
Delivered to Irrigated Lands
Diverted to Irrigation Canals
Surface Runoff
ET before returning to Water Resource Pool
Deep Percolation and Leaching
Seepage from farm ditches
By-pass Water
Seepage from Canals and Distribution Systems
Irrigation Return Flows
Available For Sequential Users
Reserved for Other Uses
Power
Recreation
Wildlife
Industrial
Flood Control
Natural and Other Uses

Figure 32. Diagram illustrating the disposition of water diverted for irrigation purposes (after Utah State University Foundation, 1969).

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does not consider other sources of supply water such as pumped groundwater or imported water. Therefore, it is applicable to the Sacramento River Basin but not to the San Joaquin River Basin because in the latter supply water is imported.

Irrigation return flow is defined as that portion of water diverted from surface and/or subsurface sources that is not consumptively lost to the atmosphere. Surface runoff, commonly referred to as tailwater, is one of the several components of irrigation return flow. Although the focus of this project was on tailwater, other components of surface return flows were also monitored since tailwater is not normally collected in a drain separate from other flows. As shown earlier in Figure 1, surface return flows may comprise of irrigation runoff, rainfall runoff, operational spills, and collected subsurface drainage. The latter may include effluents from tile drainage and drainage wells as well as interflow intercepted by open drains.

This project encountered many difficulties in estimating return flows because of lack of suitable structures to set up flow-measuring devices and small hydraulic gradients where reversal in the direction of flow frequently occurred in some drains. It was difficult to measure the quantity of tailwater without establishing flow-measuring stations between the irrigated field and the drain collector system. Moreover, other than flooded rice culture, tailwater is produced intermittently, coinciding with irrigation schedules. There is a lack of adequate data on tailwater production and its fate.

Table 42 presents a compilation of estimated tailwater production obtained from a survey of farm advisors by Dr. Ian Stewart (private communication, 1975, University of California, Davis). The values reported vary considerably and some of them appear somewhat low. It is not entirely clear whether the data reported is indicative of the more level irrigated lands in the Central Valley or if reuse of tailwater was also considered. At any rate, it has been the observation of the authors that tailwater is seldom discharged when the supply of water is limited and/or the cost of water is moderately high. Moreover, tailwater discharged is frequently reused at some downstream site even in areas of less expensive or plentiful water supply. For instance, Glenn-Colusa Irrigation District in the Sacramento Valley recirculates about one-half of the return flows generated within their district. Water discharged into the Colusa Basin Drain are further reused so that even though individual farm irrigation efficiencies may be low, overall basin efficiency of about 70% was attained in the Colusa Basin for the 1960-70 period (California Department of Water Resources, 1975).

The potential for reuse of tailwater and other surface return flows may be constrained by the water quality characteristics. Table 43 describes expected differences in the quality relative to the supply water. This approach was taken because actual concentrations of these parameters in both supply and discharge waters are highly variable from place to place. The quality of operational spills (bypass water) is not expected to be much different than the supply except for the potential pickup of sediments due to erosion of unlined channels. In contrast, some quality changes are expected in the irrigation tailwater (surface runoff). Salinity in tailwater is usually similar to that of the applied water except when there is dissolution

TABLE 42. ESTIMATED* IRRIGATION TAILWATER PRODUCTION IN THE CENTRAL VALLEY OF CALIFORNIA

Crop	Irrigation method	Percent runoff of applied water** Sacramento Valley	Percent runoff of applied water** San Joaquin Valley
Irrigated pasture	Border strip, border check	0-30 (15)	10-30 (15)
	Sprinkler	2-10 (5)	0-5
	Wild flooding	30-50 (35)	
Alfalfa	Border strip, border check	0-20 (5)	
	Sprinkler	(2)	
	Furrow		0-2
Cotton	Furrow		(<2)
	Sprinkler		(<2)
Small grains	Basin	5-15 (<5)	
	Furrow	5-15 (5)	
Rice	Basin, contour border	1-50 (25)	
Sugar beets	Furrow	5-25	0-20
Almonds, walnuts	Sprinkler	(∿0)	(∿0)
	Border, furrow, basin	0-20 (10)	0-20 (5)
Peaches, nectarines	Sprinkler	(∿0)	(∿0)
	Border, furrow, basin	(∿0)	(∿0)
Tomatoes	Furrow	0-20	0-25
	Sprinkler	(∿0)	
Other vegetables	Furrow	(5)	0-25

* Estimates derived from surveys of Farm Advisors by I. Stewart (1975), University of California, Davis.

** Range of reported values and typical in parenthesis.

of accumulated salts from surface soils. Nitrogen contents may be similar or slightly higher than the applied waters. The slight increase is usually in the organic-N form. When there is a large increase in N it is usually in the form of NH_4^+ and NO_3^- from the injection or application of N fertilizers in the irrigation water. Usually, but not always, a slight increase in biochemical oxygen demand (BOD) is expected in tailwater. Sediment concentrations are usually expected to be significantly higher because of a tendency of soils to erode but, on occasions, may be slightly less as in runoffs from flooded rice fields. Pesticide residues and P contents in tailwater vary widely like N. When pesticide and P-containing fertilizers are water-applied, their concentration levels may be slightly to significantly greater, otherwise they are not expected to be much different. Pesticides and P are to some

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TABLE 43. COLLECTED IRRIGATION RETURN FLOW COMPONENTS AND THEIR EXPECTED QUALITY CHARACTERISTICS* AS RELATED TO APPLIED WATERS

Quality parameter	Operational spills	Irrigation tailwater	Subsurface drainage
General quality	0	+	++
Salinity	0	0, +	+, ++
Nitrogen	0	0, +, ++	+, ++
Oxygen-demanding organics	0	+, 0	0, -
Sediments	0, +	++, -	0, -
Pesticide residues	0	0, +, ++	0, -, +
Phosphorus	0	0, +, ++	0, -

* 0 = not expected to be much different than supply water

+, - = some slight increase (+) or decrease (-) may occur

++ = usually expected to be significantly higher

-- = usually expected to be significantly lower

extent associated with sediments because they tend to be sorbed on soils. In general, the quality of subsurface waters is markedly different than that of the supply water. Salinity and N tend to be slightly to significantly higher because of leaching effects. On the other hand, the other quality parameters tend to be similar to the concentration or lower than that of supply water because of adsorption and filtration. Some pesticide chemicals, however, are not readily sorbed and tend to be leached through soils. Exceptions to the above observations are probable because of the many possible combinations of factors and conditions affecting these quality parameters.

To emphasize that the quantity and quality of irrigation return flows vary, comparative case study data from Glenn-Colusa Irrigation District (GCID) and Panoche Drainage District (PDD) and their relative impact on receiving streams will be presented. The quantity and quality data from GCID and PDD may be slightly different from that presented earlier to fit the available 1975 data base for the receiving streams. The calendar year 1975 was chosen since it represents more closely normal hydrologic conditions than 1977.

Table 44 recaps the quality of supply and drain waters from GCID and PDD. It shows that the supply water for GCID is of good quality and drain waters have not been appreciably degraded. The surface runoff from rice fields contributed heavily to this discharge. In contrast, the supply water for PDD is somewhat similar in quality to that of drain waters from GCID. The supply water for the latter is imported from the Sacramento River Basin. The drain

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TABLE 44. COMPARISON OF SUPPLY AND DRAIN WATER QUALITY BETWEEN GLENN-COLUSA IRRIGATION DISTRICT (GCID) AND PANOCHE DRAINAGE DISTRICT (PDD) FOR 1975.

Parameters	GCID		PDD	
	Supply	Drain	Supply	Drain
EC, mS/cm	117	418	389	2,780
TDS, mg/ℓ	116	244	219	2,050
Turbidity, JTU	9	25	31	125
SS, mg/ℓ	24	36	75	348
N in mg N/ℓ				
Total N	1.04	1.31	1.13	13.5
Org. N	0.87	1.03	0.46	0.70
NH_4	0.03	0.07	0.05	0.10
NO_3	0.14	0.19	0.62	12.6
Boron	-	-	0.1	4.3

water from PDD is appreciably degraded mainly due to tile drainage effluents from salt-affected lands. It is not entirely certain how long these high concentrations of salinity, NO_3-N, and boron will persist because their sources sources in the soils are large and high water table conditions are becoming more widespread. It is expected that such quality problems will persist for decades (San Joaquin Valley Interagency Drainage Program, 1979). The moderate concentrations of suspended matter in return flow are derived from surface irrigation of the highly erodible Panoche soil series as well as erosion of drain channel banks. It is of interest to note that N discharged from GCID was lower in concentration and dominated by organic N while that from PDD was much higher in concentration and dominated by NO_3-N.

Table 45 gives the total annual mass and unit annual mass inputs and outputs of water and quality parameters for GCID and PDD. The total mass of quality constituents are obtained from the product of water volume and concentration. Unit mass data are obtained by taking the quotient of total mass and land area, and they allow direct comparisons between districts of different sizes. Note the difference in unit applications of water and unit drainage. This large difference in application rate of water as well as

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TABLE 45. COMPARISON OF ANNUAL MASS INFLOW AND OUTFLOW OF WATER, SALTS, SUSPENDED MATTER, AND NITROGEN BETWEEN GCID AND PDD FOR 1975.

Parameter	GCID		PDD	
	Supply	Drain	Supply	Drain
Water, $10^6 m^3$	1,030	300	158.9	48.8
, m^3/m^2	1.92	0.56	0.98	0.30
, ac-ft/ac	6.31	1.84	3.21	0.99
TDS, tons	119,570	73,300	34,810	100,370
, $tons/km^2$	223	137	195	564
, tons/ac	1.00	0.61	0.96	2.76
SS, tons	24,740	10,810	11,910	17,020
, $tons/km^2$	46	20	67	96
, tons/ac	0.21	0.09	0.33	0.47
Total N, tons	1,070	394	180	660
, $tons/km^2$	2.00	0.73	1.01	3.71
, lbs/ac	18	6	10	36
NO_3-N, tons	144	57	99	616
, $tons/km^2$	0.27	0.11	0.56	3.46
, lbs/ ac	2.4	1.0	5.4	33.8

drainage is mainly due to flooded rice culture dominating in GCID and furrow irrigated row crops dominating in PDD. The percent of applied waters drained, however, are both about 30%.

For GCID, although the concentration of TDS in drain water was 2.1 times greater than the supply water, the mass of TDS discharged was less because the volume of drain water was much smaller than that of the supply water. In contrast, the concentration of TDS in drain water from PDD was 9.4 times greater than the supply water and the mass of TDS discharged was 2.9 times greater than that brought in with the supply water. Therefore, in GCID there was a net loss in the mass of TDS, some of which was lost through deep percolation and precipitation as mineral salts, while in PDD there was a net gain in TDS, largely due to the leaching of accumulated soluble salts and chemical weathering of gypsum that are naturally present in the soils. Note that both districts applied about 200 tons/km2 of TDS through their supply water.

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In GCID, although the concentration of SS was slightly higher in the drain as compared to the supply water, the mass emission rate of SS was only about 44% because of the same reason cited for TDS. By contrast, in spite of the concentrations of SS being 4.6 times greater in the drain as compared to the supply water in PDD, the mass emission was only 1.4 times greater. In GCID the concentration of NO_3-N discharged was 1.4 times greater than the supply water but the mass emission was only 0.3 times greater. Conversely, the NO_3-N in drain water from PDD was 20.3 times greater in concentration and mass emission only 1.4 times greater.

The above examples emphasize that both concentration and unit mass emission need to be considered when evaluating surface irrigation return flows, and they vary widely between these two districts because of site specific conditions and factors.

The surface return flows from GCID and PDD are not discharged directly into surface receiving waters because the district outflows are far removed from the stream. Moreover, the district outflows are extensively reused by others downstream. In the case of GCID, supply water is diverted from the Sacramento River and return flows are ultimately discharged back into the same river system. In contrast, supply water for PDD is imported from the Sacramento River Basin while the drain waters are ultimately discharged in the middle reaches of the San Joaquin River. In view of such complexity in the distribution and drainage of water, Table 46 appraises the quality and flow of district outflow, regional outfall, and receiving streams.

Because of the comparatively large flows in the Sacramento River, the contribution of drainage water and its quality from GCID and other downstream dischargers through the Colusa Basin are relatively insignificant. However, it should be pointed out that a turbid plume is usually visible at the outfall of Colusa Basin Drain into the Sacramento River near Knights Landing. In contrast, the flow in the middle reaches of the San Joaquin River during the irrigation is largely made up of return flows from the west as well as east sides of the San Joaquin Valley in the vicinity of this project study area. The quality of the east side return flows is generally better than those of the west side since the soils in the former area are nonsaline while those in the latter are saline to varying degrees.

Table 46 points out that the flow and quality aspects for the San Joaquin Valley site is quite different than in the Sacramento Valley site. The outfall of Salt Slough contains a larger volume than the outflow from PDD since this slough conveys return flows from several water districts as well as return flows from captured and reused drain water from wildlife areas. Salt Slough contributed about 61% of the flow in the San Joaquin River as measured at Fremont Ford. Salt Slough also contributed 79, 54, and 147% of the TDS, SS, and NO_3 respectively, to the San Joaquin River. The mass of NO_3-N in the San Joaquin River at Fremont Ford is less than that discharged from the outfall of Salt Slough because of assimilation by phytoplankton and other aquatic plants, and possibly denitrification. The contributions of quality inputs from PDD into Salt Slough (and ultimately into the San Joaquin River) are estimated to be exceedingly large by this appraisal methodology. However, because of the extensive reuse made of PDD's drain water, the mass of TDS,

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TABLE 46. IMPACT OF DISTRICT OUTFLOWS AND REGIONAL OUTFALLS ON RECEIVING STREAMS

Parameter	Sacramento River			San Joaquin River		
	Glenn-Colusa Irrigation District Outflow	Colusa Basin Drain Outfall	Sacramento River below Knights Landing	Panoche Drainage District Outflow	Salt Slough Outfall	San Joaquin River at Fremont Ford
Water, 10^6 m^3	300	267	5,220	48.8	56.8	93.7
, % contribution*	6	5	-	52	61	-
TDS, mg/ℓ	244	427	125	2,050	821	627
, tons	73,300	114,090	652,680	100,370	46,610	58,800
, % contribution*	11	17	-	171	79	-
SS, mg/ℓ	36	111	66	348	91	103
, tons	10,810	29,660	344,610	17,020	5,170	9,660
, % contribution*	3	9	-	176	54	-
NO_3-N, mg/ℓ	0.19	0.14	0.90	12.6	1.75	0.73
, tons	57	37	470	616	100	68
, % contribution*	12	8	-	906	147	-

* % of receiving stream

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SS and NO_3-N in Salt Slough are substantially reduced in spite of outflows from other sources. As drain water from PDD is reused by the Grasslands Water District and others, TDS accumulates as soluble and precipitated salts in the basin soils of the GWD and wildlife habitats. Similarly, SS discharged by PDD are deposited in the flatter wetland and upland habitats as current velocity is reduced substantially. The drain channels in the wildlife habitat need to undergo periodic dredging due to sediment deposition. The NO_3-N in drain waters applied to native pastures and duck ponds are taken up to some extent by vegetation and/or is denitrified since there is more soluble organic carbon present in the basin waters than in return flows from upslope irrigated lands.

The above data and interpretations document the complexity of evaluating irrigation return flows in terms of both production and impact. It is clear that recommendations on return flow management require case by case analysis.

POTENTIAL BEST MANAGEMENT PRACTICES

Due to the wide variability in the quantity and quality of tailwater and other return flows, best management practices (BMP) should be developed on the basis of site specific conditions. With due recognition to this caveat, an array of potential controls and management of tailwater is summarized in Figure 33. These tailwater control and management practices consist of on-farm and off-farm technologies as well as nonstructural and structural technologies.

In most instances, one of the better alternatives is to recover and reuse tailwater and other return flows at district and basin levels. Where there are no quality constraints such as excessive salinity or boron, tailwater may be captured and directly reused. For instance, Glenn-Colusa Irrigation District recirculates about half of their drain waters. Where there are quality constraints, such as excessive salinity or boron, the irrigation return flow may be reused by blending with freshwater. For instance, Broadview Water District collects and reuses all of their return flows generated within their district as well as some inflows from contiguous irrigated lands. The delivered supply water is a half and half blend of fresh canal water and saline return flows. This unique practice, however, requires adequate leaching of the crop root zone as well as deep percolation beyond the root zone. When the quality is no longer usable for crop irrigation, other beneficial uses can be made of irrigation return flows. The 13×10^6 m^2 (3,200 ac) Los Banos Wildlife Area diverted more than 30×10^6 m^3 (24,000 ac-ft) in 1975 as well as in 1976 for the irrigation of feed and cover for wildlife, fish ponds and duck ponds, and maintenance of marshlands. Recovery and reuse may be practical not only at district and basin levels but also at the on-farm level.

In most other instances, BMP for tailwater production and management may be source control, i.e., if tailwater production is controlled, irrigation application efficiency would be improved, water and energy would be conserved, and, at the same time, water pollution problems would be reduced. Technology for curtailing tailwater production is available but its applicability will depend on local conditions and cost benefits. A properly designed and

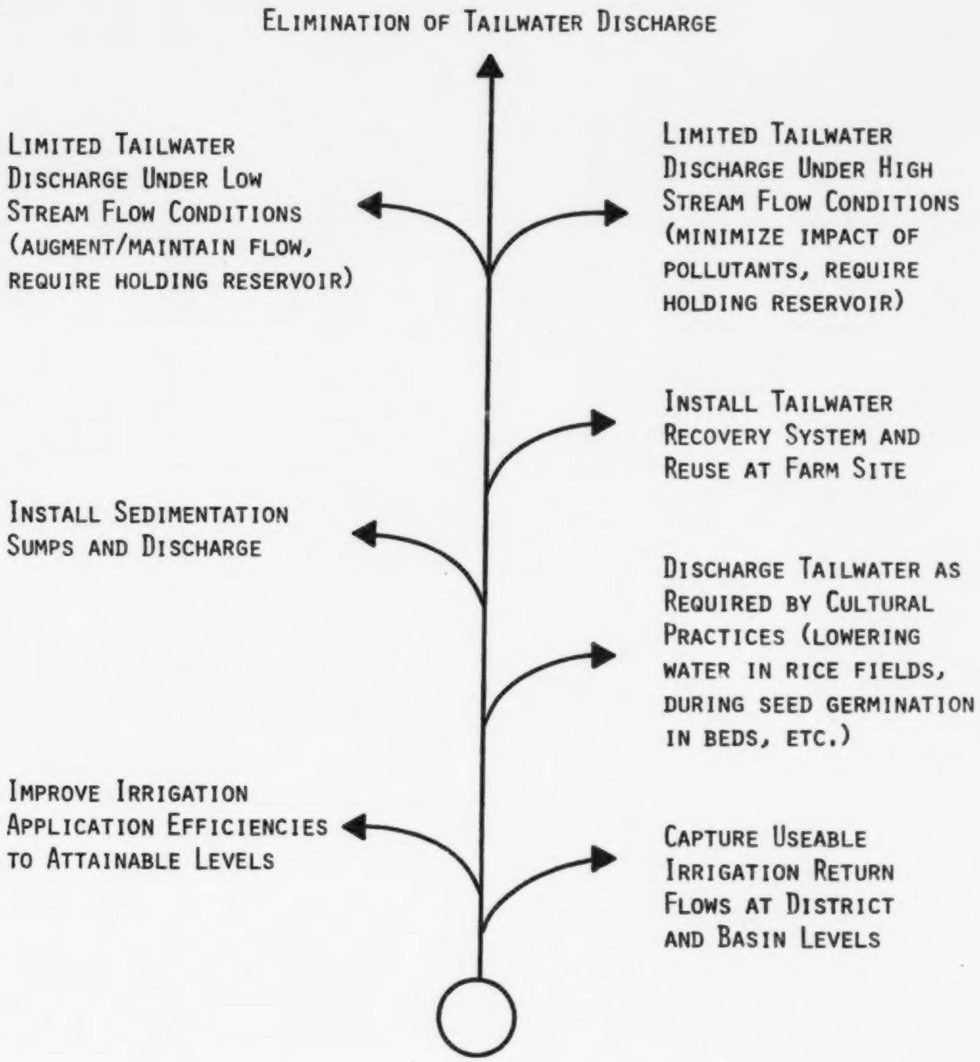
ELIMINATION OF TAILWATER DISCHARGE
LIMITED TAILWATER DISCHARGE UNDER LOW STREAM FLOW CONDITIONS (AUGMENT/MAINTAIN FLOW, REQUIRE HOLDING RESERVOIR)
LIMITED TAILWATER DISCHARGE UNDER HIGH STREAM FLOW CONDITIONS (MINIMIZE IMPACT OF POLLUTANTS, REQUIRE HOLDING RESERVOIR)
INSTALL TAILWATER RECOVERY SYSTEM AND REUSE AT FARM SITE
INSTALL SEDIMENTATION SUMPS AND DISCHARGE
DISCHARGE TAILWATER AS REQUIRED BY CULTURAL PRACTICES (LOWERING WATER IN RICE FIELDS, DURING SEED GERMINATION IN BEDS, ETC.)
IMPROVE IRRIGATION APPLICATION EFFICIENCIES TO ATTAINABLE LEVELS
CAPTURE USEABLE IRRIGATION RETURN FLOWS AT DISTRICT AND BASIN LEVELS

Figure 33. Alternative tailwater control practices.

operated sprinkler system should not yield tailwater. The efficiency of surface irrigation methods can also be improved, for example, by land levelling, contour irrigation, cutting back stream size, and reducing length of run. Any practice or technology that contributes to improve irrigation to attainable application efficiencies will reduce tailwater production.

In some instances, tailwater may need to be unavoidably discharged. In California, paddy rice is continuously flooded throughout the growing season, except for two occasions. Flood waters in rice fields are lowered in the early growing season, usually in late May and June, to prevent erosion of levees during gusty winds, and/or after the water-application of herbicides, to prevent damage to rice seedlings (some of the herbicides have deleterious

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effects on rice if kept in contact sufficiently long). Rice fields are also drained in the latter part of the growing season, usually in late August and September, prior to harvest. This practice of spilling flood waters before harvest can be minimized if irrigators cut off irrigation earlier, taking into account projected seepage and ET losses. Growers who attempt to germinate seeds in furrow beds practice frequent irrigations. This practice results in low irrigation efficiency and significant tailwater production because it is not usually possible to get light and frequent irrigations to wet across the furrow bed. One potential management solution is to use sprinkler irrigation for germination, followed by furrow irrigation later. Such a practice is used by some irrigators in the Panoche Water District to germinate lettuce, and other crops.

Where soil erosion and sediment production is a problem, the BMP may involve control at its source (Carter and Bondurant, 1976) or removal of sediment (Fitzsimmons et al., 1977). Sediments in tailwater may be settled out in sediment retention ponds or tanks, vegetated buffer strips like grass and barley, and other such on-farm facilities. It should be noted that not all of the sediments found in drainage canals originate from tailwater. Some of these sediments are derived from erosion of ditch and canal banks as in Panoche Water District because the soils are rather unstable or from the resuspension of sediments previously deposited from winter storm runoffs as in Glenn-Colusa Irrigation District. Under certain conditions, in spite of sediment removal structures, not all the sediments would settle out because of their highly dispersed nature. For example, Tehama silt loam in the Sacramento Valley tends to remain suspended because of an apparent unique soil mineral assemblage while basin soils in the San Joaquin Valley also tend to remain dispersed because of excessive concentrations of exchangeable sodium. In the study site used by the authors in the San Joaquin Valley, sediments in collected irrigation return flows were deposited in significant amounts as the return flow was reused in irrigated pastures and duck and fish ponds.

At the field and on-farm level, it may be desirable to install tailwater recovery systems. According to Schulbach and Meyer (1979), the costs of a tailwater recovery system will range from less than $1,000 to more than $12,000. This wide range of costs is due to differences in amount of water to be recovered and the size of sump pump to handle this quantity as well as distance to point of reuse. The economic appraisal for alternative irrigation systems including tailwater recovery for a tomato field in Panoche Water District indicates comparable costs and benefits between hand move sprinkler system and furrow irrigation recirculation system.

At district and regional spatial levels, other alternative BMP's may include limited discharge of tailwater into receiving streams. This may require holding reservoirs. On the one hand, tailwater may be discharged under low flow conditions to augment or maintain flows. In the Mendota-Crows Landing Return Flow Group, the irrigation return flows contribute to maintenance of summer flows in the middle reaches of the San Joaquin River for a variety of beneficial uses. On the other hand, tailwater and other return flows having degraded water quality may be discharged only under high flow conditions to minimize the quality impacts.

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One other possible alternative is to eliminate tailwater discharge. This alternative is considered to be too stringent and is not practical or feasible for the Central Valley of California. Moreover, tailwater control and reuse may not be desirable in some instances and should be viewed in the light of other water management plans and policies. For instance, a large reduction in tailwater and other return flows may lead to other potential problems such as diminished supply of water for subsequent or downstream water uses, a diminished summer flow in streams, and for the Sacramento-San Joaquin Delta inadequate flow to repel seawater intrusion.

There appears to be no one universal control technology for tailwater and other collected irrigation return flows. One reasonable BMP involves achieving attainable irrigation efficiencies, taking into account evapotranspiration losses and need for salt control and seed germination. This BMP falls in the category of nonstructural, on-farm performance technology. A second reasonable BMP is to recover usable return flows at downstream sites by irrigators and other users. This BMP is an off-farm practice that requires some structure to recover and distribute the captured return flows. A third BMP would be the use of tailwater recovery systems at the on-farm level. It is the considered opinion of the authors that surface irrigation methods will continue to be used in the future, albeit at better efficiencies than in the past because of water conservation and energy needs, and will not be completely replaced by sprinkler or drip irrigation. This means that some tailwater production would be inevitable and measures should be taken to recover and reuse this source of water.

All of the aforementioned BMP's are practiced to varying degrees by irrigated agriculture in California and elsewhere. The application of the array of BMP's given in Figure 33 should be considered on a case by case basis. Although some of the BMP's can be broadly applied, there is no single, universally-applicable control technology for tailwater because of site specific conditions and factors.

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1. Project study area tour attended by 29 participants in the San Joaquin Valley and 23 in the Sacramento Valley. October, 1975.
2. Project study area tour attended by 41 participants in the San Joaquin Valley and 35 in the Sacramento Valley. July, 1976.
3. Aerial tour on water resources development and water quality pollution problems in the Central Valley for Dr. Russell Train and his staff from U.S. Environmental Protection Agency. September, 1976.

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1. Point-Source Irrigation Return Flows and the NPDES Permit System, Westside Association of Resource Conservation Districts, Los Banos California. September, 1975.
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3. Summary of the 1975-76 Annual Report to EPA, Grant No. R-803603. Public Meeting, Irrigation Tailwater Management, Los Banos, California. July, 1976.
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5. Irrigation Return Flow in the Central Valley. Advisory Committee on Agricultural Water Quality, State Water Resources Control Board, Sacramento, California. March, 1977.
6. Evaluation of Surface Irrigation Return Flows in the Central Valley of California. National Conference on Irrigation Return Flow Quality Management, Fort Collins, Colorado. May, 1977.
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